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PREPARATION OF MANUSCRIPTS

It will be most appreciated if authors of papers to be submitted to the *Journal of Geological Education* will follow these simple directions.

(1) Make your paper as concise as possible.

(2) On the first page, start typing at least three inches down from the top. It is convenient to have title, author's name and institution, and a brief informative abstract, all on the first page.

(3) Follow the format of papers published in recent issues of the *Journal*.

(4) Double-space *everything*—abstract, text, tables, quotations, reference list.

(5) *Type* simple tables, such as lists; they will be set in print. *Draft and letter* complicated tables, involving ruled spaces, special symbols, etc.; they will be reproduced photographically.

(6) Include line drawings only if essential to your subject. Photographs are ordinarily not acceptable.

Journal of Geological Education

Volume 9 Fall 1961 Number 2

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A COURSE IN STATISTICAL GEOLOGY (GEOMETRICS)

J. F. HUBERT

University of Missouri

ABSTRACT. The statistical analysis of quantitative data in geology is playing an important role in the expansion of geology into an interdisciplinary science. A detailed outline is presented of the statistical geology (geometrics) course taught at the senior-graduate level for three semester hours' credit at the University of Missouri. The course has stimulated interest in the design of experiments in many areas of geology and has strengthened the graduate research program.

INTRODUCTION

Perhaps the outstanding development in geology in the past fifteen years is the increasing quantification of our science. This trend has helped to make geology a true interdisciplinary science, drawing for support on mathematics, chemistry, physics, and biology, but retaining its inherent flavor as the history of the earth. The current changes in the curricula of many geology departments reflect this development, with courses now common in geochemistry, geophysics, paleoecology, crystal structure, and other relatively new areas. A glance at the recent geological literature shows that the trend toward the generation and statistical analysis of quantitative data in many types of geological problems is well established. Use of quantitative methods in geology seems headed for certain expansion in the future, and the introduction of a statistical geology course in the geological curriculum could be profitably considered by many departments. This paper describes the course now taught at the University of Missouri, and evaluates the effects of the course on geological education and student research.

OBJECTIVES OF GEOMETRICS

At the University of Missouri a statistical geology course is taught during the Fall semester for three semester hours' credit at the senior and graduate-student level. The course is called geometrics, following the suggestion of Dr. J. C. Griffiths who introduced the term several years ago at The Pennsylvania State University. The objectives of geometrics are twofold. First, the student must be able to assimilate the literature intelligently where statistical methods are an integral part of the research. Secondly, each student should be familiar with a sufficiently large variety of statistical methods to enable him to plan his own

experimental designs and sampling programs, successfully carry out the work, and prepare the results for presentation in thesis and publication form. These objectives imply that a geometrics course should include most of the more useful statistical methods and involve considerable assigned reading of geological papers that involve statistical analysis. In the two years that geometrics has been taught, the course has been taken largely by graduate students, who can see the immediate benefits of statistical training in reading the geological literature and in planning their thesis research. An elementary statistics course is not a prerequisite, although some students have this background and it is highly desirable.

COURSE OUTLINE AND READING ASSIGNMENTS

The material covered in geometrics in the 16-week semester is presented below.

Week

1 and 2 History of statistical applications in geology. Basic concepts and vocabulary: population, random sample, statistic, parameter, frequency distribution, precision, accuracy, mean, standard deviation, etc.

3 Measurement theory: nominal, ordinal, interval, and ratio scales with the appropriate statistical measures for each.

4 Probability theory.

5 Critique of statistical hypothesis testing and the scientific method: (i) null hypothesis and research hypothesis, (ii) choice of the statistical test and power of the test, (iii) level of significance and sample size, (iv) sampling distribution of the test statistic, (v) region of rejection, and (vi) the decision.

6 The binomial and normal distributions. Quality control of experimental techniques.

7 Chi-square distribution and Chi-square test.

8 t-distribution and t-test. Confidence limits on the population mean and variance.

9 Nonparametric alternatives: Mann-Whitney U-test and Moses test of extreme reactions.

10, 11, 12 Linear regression and correlation. Nonparametric alternative: Spearman rank correlation coefficient.

13, 14 Analysis of variance with one factor. Bartlett's test of homogeneity of variance. Tukey's D-test for all comparisons among means. Nonparametric alternative: Kruskal-Wallis one-way analysis of variance.

15, 16 Analysis of variance with two factors and hierarchical sampling: random, fixed, and mixed models. Analysis of the components of the expected mean squares. Nonparametric alternative: Friedman two-way analysis of variance.

At present there is no text specifically written for statistical methods in geology. Several books are in preparation, and within a few years at least two should be available. In the interim, either Snedecor's *Statistical Methods*, 5th Edition (Iowa State College Press, Ames, 1956, 534 pp.), written for agronomy students, or *Quantitative Zoology*, Revised Edition, by Simpson, Roe, and Lewontin (Harcourt, Brace and Co., New York, 1960, 440 pp.) are excellent senior-graduate level texts easily adaptable to geometrics.

The course outline for geometrics differs significantly from that of most applied statistics texts because it gives extended coverage to both the classical

parametric and the more recently developed nonparametric (distribution-free) experimental designs. The number and variety of nonparametric tests have increased rapidly in the last ten years, as has the rate at which they are being introduced. Nonparametric methods seem destined to occupy a much more important place in geological research in future years than they do now, both because the quantitative data often fail to meet the assumption of normality and because ordinal (ranking) data are fairly common in geology. The assumptions, as well as the obvious usefulness, of the mathematical models of the parametric tests are emphasized, together with the statistical consequences when the assumptions are not met. This approach inculcates a more appreciative and cautious outlook toward statistics, and may help to avoid misapplication of statistical techniques during the present transition period of expansion of statistical analysis in geological research.

Nonparametric tests have their most obvious application in research in the behavioral sciences, where the raw scores frequently can only be ranked, rather than equated to a true quantitative scale on which arithmetic means and standard deviations can be calculated. Consequently, measurement theory and nonparametric experimental designs are emphasized more in texts in the behavioral sciences than in the natural sciences. The basic reading for nonparametric texts in geometrics is assigned in Siegel's *Nonparametric Statistics for the Behavioral Sciences* (McGraw-Hill Book Co., Inc., New York, 1956, 312 pp.), which contains an excellent summary of 24 nonparametric tests.

The large applied-statistics literature in the natural sciences provides a valuable selection of reading assignments for geometrics. The history of applied statistics in many fields of learning is reviewed by Sir Ronald A. Fisher, the "father of applied statistics", in "The expansion of statistics" (*American Scientist*, vol. 42, 1954, pp. 275-282 and 292-293). This paper contains an interesting discussion of one of the earliest applications of statistics to the natural sciences, by Lyell in 1830-33, when he established most of the Tertiary epoch names on the basis of the proportions of living species, largely marine mollusks, found as fossils in the rocks of the Paris Basin. Miller summarized the work accomplished in statistical geology to 1953 in his "Introduction to the statistics issues" of the *Journal of Geology* (vol. 61, 1953, pp. 479-481). The paper by Mayne on "The role of statistics in scientific research" (*The Scientific Monthly*, vol. 84, 1957, pp. 26-33), one of many articles and books on the "scientific method", discusses the role of probability theory and hypothesis testing in experimental design. Huff's *How to Lie with Statistics* (Norton and Co., New York, 1954, 142 pp.) and Huff and Geis' *How to Take a Chance* (Norton and Co., New York, 1959, 173 pp.) are humorously illustrated, highly entertaining, and very instructive books, on the graphic presentation of summary statistics and the everyday application of probability theory. This sample of additional reading material assigned in geometrics should of course be modified and expanded at the discretion of the instructor, and should be integrated with the classroom lecture and laboratory material.

STATISTICAL GEOLOGY LABORATORY

Experience has convinced me that the really effective and permanent mastering of statistical methods takes place in the laboratory, where the students examine geological data using specific statistical techniques. If only a textbook approach is used in teaching statistics, as in a mathematics course, then it is a rare student indeed who can grasp the wide range of applications in geology. The fundamental importance of the laboratory is emphasized by the fact that auditors of the course who do not do the laboratory work are soon unable to understand the lecture material. Although statistical methods were first used, and are still most widely applied, in sedimentology, it is important to demonstrate through varied laboratory problems their useful applications in paleontology, physiography, igneous petrology, glaciology, and other areas. The laboratory exercises involve published geological data, drawn from articles to which the students are referred, and none is based on invented data or on data simplified to one or two digits. Where feasible, the preliminary summary statistics, such as the sum of squares, are provided to reduce the amount of "busy-work" computations. The students do acquire, however, a reasonable degree of facility with various types of desk calculators.

EFFECT OF GEOMETRICS ON STUDENT RESEARCH

Geometrics bears the same relation to geological research as the geological hammer: it is a tool, to be used when needed. As a science progresses from a largely descriptive to a more quantitative stage, more elaborate and refined tools are usually necessary. Geometrics attempts to provide a sufficiently broad assemblage of the basic statistical techniques most commonly used in the geological literature that the student can draw on them as necessary in his thesis research. From this repertoire of techniques, he can select the particular statistical design appropriate for his geological problem. After geometrics was taught for the first time, a number of graduate students used statistical methods in research in several divergent areas of geology.

As in any geology course, geometrics can only expose the student to the basic philosophy and the most valuable techniques. Real facility with quantitative analysis comes only through application of the techniques to specific research problems. When using an unfamiliar statistical test, or a complicated statistical sampling design, students are encouraged, both now and in their future work, to consult an expert in applied statistics. Geometrics fulfills the major function of enabling the student to phrase his questions in a precise and meaningful way, and to evaluate intelligently the answers of the more experienced statistician and apply them to his particular research problem.

As the student gains proficiency in the design and analysis of experiments, he may develop a curiosity about more advanced statistical procedures. To satisfy this interest, a geology department may offer an advanced, second semester of statistical geology, or a seminar in statistical methods molded to the interests of the students; or it may encourage a minor in statistics, in lieu of the second foreign language required for the Ph.D. degree. In some areas of geology, such as sedimentology, a knowledge of advanced statistical theory is essential for effective

research. Consequently every university administration should be encouraged to find formal ways by which a student's program can accommodate more work in statistics. A minor in statistics, for example, normally requires the student to take advanced courses in applied statistics outside geology, and so become acquainted with the philosophy of experimental design of other fields, aiding the "cross-fertilization" among departments which has proved of such great value to geology.

While taking a statistical geology course, the student should become familiar with the practical usefulness of a digital computer as a research tool. The University of Missouri provides mathematical, statistical, and programming consultants free of charge to students and faculty for its Burroughs 205 (Datatron) digital computer at its Computer Research Center. A two-week introductory course in programming the computer is available to students and faculty in the evenings, to acquaint them with the capabilities and limitations of the computer. In geometrics the students learn some of the types of problems particularly suitable for analysis in a digital computer, such as multiple regression with five or more variables, although it is neither possible nor necessary to become fully conversant with the details of the operation and programming of the computer.

Acknowledgments

I should like to express my appreciation to Professors W. D. Keller and A. G. Unklesbay of the Department of Geology of the University of Missouri for critically reading the manuscript of this paper.

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SPACE RELATIONS TEST AS A MEASURE OF VISUALIZATION ABILITY

WILLIAM R. MUEHLBERGER and ROBERT E. BOYER
The University of Texas

ABSTRACT. For three years a *Space Relations* test has been given to the geology and petroleum engineering majors at The University of Texas, at the beginning of the structural geology course. Results of this test, given to over 200 students during this time, indicate a positive correlation between performance on the test and final grades in courses in structural geology and mineralogy, as well as the average of grades in structural geology and all prerequisite geology courses. A student scoring 80 or higher has better than even odds of receiving an "A" or "B" in mineralogy and structural geology. Below 65, he has only 1 to 6 odds of an "A" or "B" and nearly even odds to make a "D" or "F" in either course. Further, the test should indicate a large proportion of the potential graduate geology students at an early stage in their programs. It would be profitable to give the *Space Relations* test to all beginning geology majors, thus enabling an early evaluation of their ability in visualization.

The ability to visualize in three dimensions is one of the greatest assets a capable geologist may have, regardless of his field of emphasis.

During the past 3 years, the students taking structural geology at The University of Texas have been given a *Differential Aptitude Test* entitled *Space*

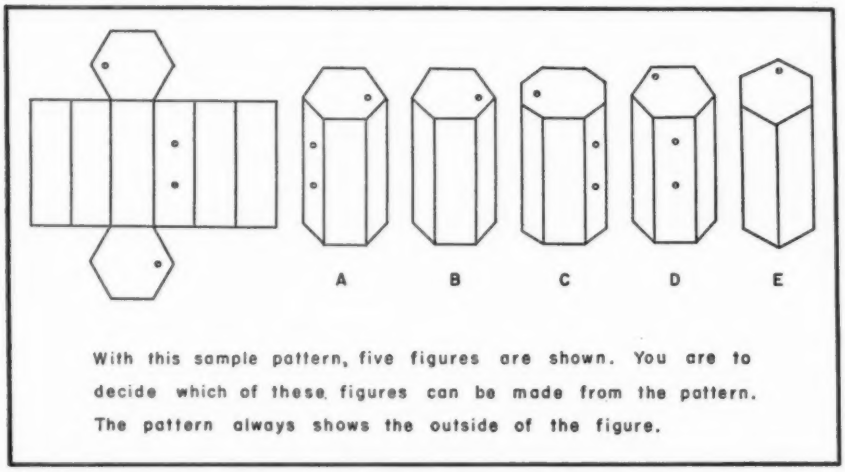
A
B
C
D
E
With this sample pattern, five figures are shown. You are to decide which of these figures can be made from the pattern. The pattern always shows the outside of the figure.

FIG. 1. Type of pattern and figures used in the *Space Relations* test. Note that answers B and D are both correct.

Relations. The test, given at the beginning of the first laboratory session, takes 30 minutes to administer. It consists of 40 patterns; with each pattern five figures are shown and the student decides which figures can be made from that pattern. There are 100 possible correct answers, therefore several figures per pattern are possible. Figure 1 is an example of the type of pattern and figures used. This test is one of a set of eight *Differential Aptitude Tests* made up by the Psychological Corporation of New York City and administered to our classes by the Testing and Counseling Center of The University of Texas. Many schools have a similar testing service from which this test may be obtained, but for those who do not, the test is available by ordering directly from the Psychological Corporation.

Structural geology is taught at the junior level, and consists of two 1-hour lectures and one 3-hour laboratory session per week for one semester. It is a required course at The University of Texas for both geology and petroleum engineering majors. The petroleum engineering majors are invariably seniors, and have had descriptive geometry and more mathematics, chemistry, physics, and engineering courses than the geology majors, who are usually juniors. For this reason, and because they have different motivation, the test results of the two groups are compared separately in each of the following analyses in addition to being treated as a unit. The following sets of data are compared against the raw score performance on the *Space Relations* test:

1) Letter grade in structural geology course.
2) Letter grade in mineralogy course.
3) Numerical average of letter grades of structural geology and all prerequisite geology courses (physical geology, historical geology, mineralogy, and petrology).

Figure 2 is a plot of the letter grade received in structural geology and the raw score on the *Space Relations* test. All three graphs show consistent trends as reflected by the means, although the relationships differ slightly. Whereas the mean for geology majors (Fig. 2, A) has a rather uniform increase with each higher letter grade, that for the petroleum engineering majors (Fig. 2, B) shows a marked increase between the F to D and C to B levels, with very little increment between D and C. This is most satisfactorily explained by the incentive factor involved. A minimum "C" grade is required of geology majors for credit in the course; the petroleum engineering majors get credit for a minimum "D" grade. Therefore, a number of petroleum engineering majors who are potential "C" students put out less effort and get a "D" grade. This results in a higher "D" mean and a lower "C" mean as shown on Figure 2, B.

The combined graph (Fig. 2, C) is helpful to predict the likelihood of a student's success in the course on the basis of his performance on the *Space Relations* test. Based on this graph, any student who gets 80 or above on the test has better than 7 to 1 odds to get a "C" grade or higher, better than even odds to get an "A" or "B", only 1 to 9 odds to get a "D" or "F" in structural geology. If, on the other hand, his test grade is below 65, he has only 1 to 6 odds of an "A" or "B"; below 60, he has even odds of getting a "D" or "F" in the course. The need

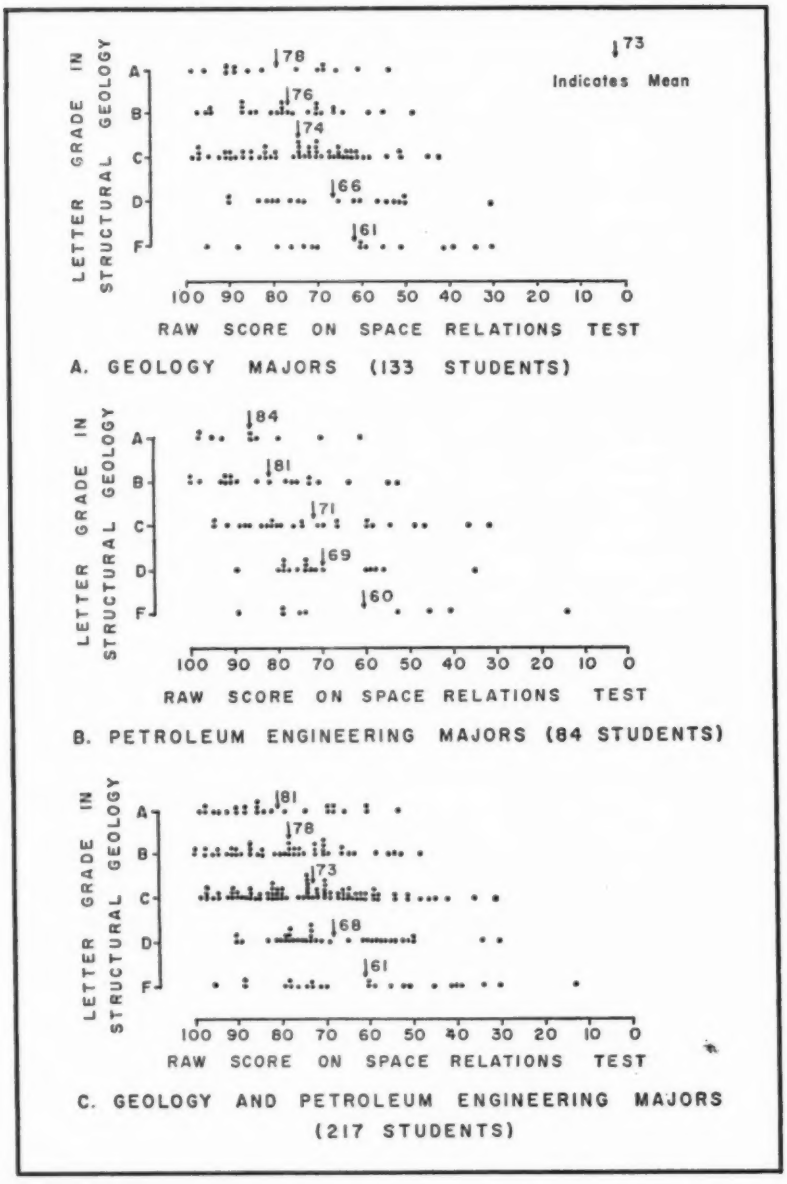

FIG. 2. Plot of structural geology letter grades versus raw scores on *Space Relations* test.

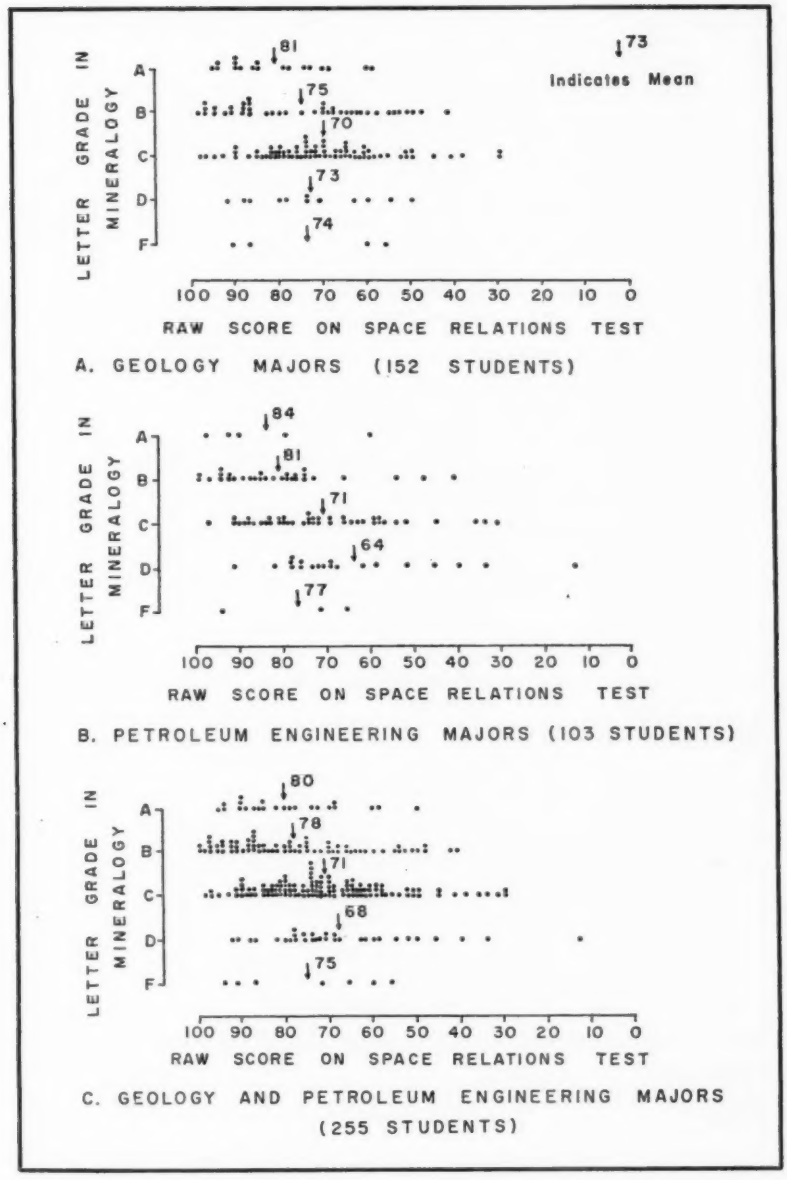

FIG. 3. Plot of mineralogy letter grades versus raw scores on *Space Relations* test.

to get an "A" or "B" should be obvious to all students who plan to continue their studies into graduate school. In other words, little demand exists for the "C" student in the geologic profession.

It is significant to note the marked anomalies to the general trends shown. For example, Figure 2, C indicates one student who received an "F" grade but scored 95 on the test, and another who received an "A" but scored only 53. On talking with the students, we learned that a few of these anomalies were the result of outside jobs, illness, or failure to try hard enough on the test. Most of the anomalies, however, are real, and justify our opinion that (1) hard work can compensate for some lack of ability to visualize; (2) work (other than visualization abilities) is required to pass the course; and (3) the ability to visualize can be cultivated.

Our plot of grades received in mineralogy versus raw scores on the *Space Relations* test (Figure 3) shows nearly identical odds for predicted grades in this course as in structural geology. The graph is incomplete because it includes only those who later took structural geology. The bulk of the students who fail mineralogy drop out of geology rather than attempt to repeat the course. On the other hand, of the geology majors who received "D" or "F" on their first attempt in mineralogy and repeated the course, 6 out of the 7 scoring 79 or better raised their grade to a "B" on the second try, whereas only 1 of the 9 below 79 raised his grade to a "B". The remainder of the repeat group made "C" on their second try.

Figure 4 is a plot of the correlation between the average of letter grades in structural geology and the four prerequisite geology courses versus the raw score in the *Space Relations* test. Grade averages were computed on a 5-point system with F=1, D=2, C=3, B=4, A=5. In cases where a student received a failing grade in a course and then repeated it, the additional grade was included in the average.

In order to check the significance of these plots, the coefficient of correlation for each diagram of Figure 4 was calculated according to the formula

$$r = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{[N\Sigma X^2 - (\Sigma X)^2][N\Sigma Y^2 - (\Sigma Y)^2]}}$$

as suggested by Croxton and Cowden (1939, p. 672). "N" is the sample size, "X" represents the individual grade average, and "Y" is the individual raw score performance on the *Space Relations* test. The coefficient of correlation, "r," is not high for any of the groups compared in Figure 4, although it does show a positive correlation.

The 95-percent confidence limits for the correlation coefficients of the three diagrams of Figure 4 were established using Freund (1952, Table VI, p. 395). The confidence limits for all three coefficients ranged considerably, but demonstrated the positive correlation.

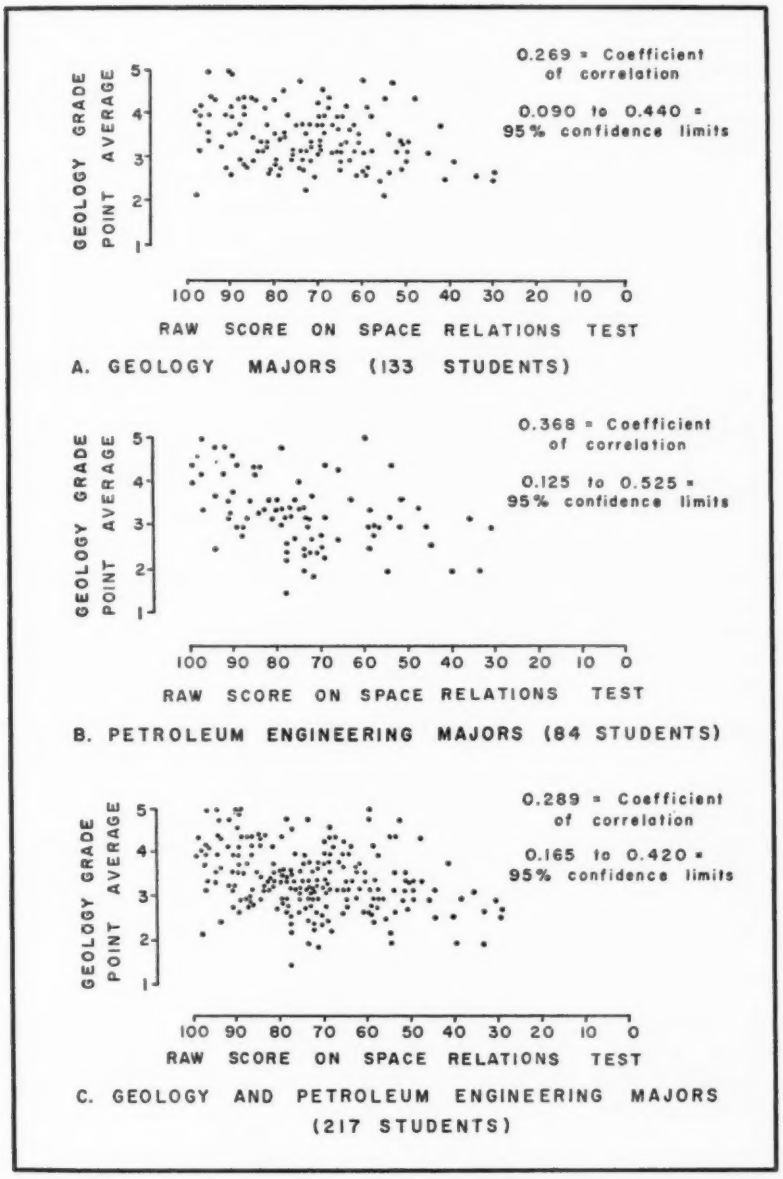
0.269 = Coefficient of correlation
0.090 to 0.440 = 95% confidence limits
GEOLOGY GRADE POINT AVERAGE
5
4
3
2
1
100 90 80 70 60 50 40 30 20 10 0
RAW SCORE ON SPACE RELATIONS TEST
A. GEOLOGY MAJORS (133 STUDENTS)
0.368 = Coefficient of correlation
0.125 to 0.525 = 95% confidence limits
GEOLOGY GRADE POINT AVERAGE
5
4
3
2
1
100 90 80 70 60 50 40 30 20 10 0
RAW SCORE ON SPACE RELATIONS TEST
B. PETROLEUM ENGINEERING MAJORS (84 STUDENTS)
0.289 = Coefficient of correlation
0.165 to 0.420 = 95% confidence limits
GEOLOGY GRADE POINT AVERAGE
5
4
3
2
1
100 90 80 70 60 50 40 30 20 10 0
RAW SCORE ON SPACE RELATIONS TEST
C. GEOLOGY AND PETROLEUM ENGINEERING MAJORS (217 STUDENTS)

FIG. 4. Plot of grade-point averages in structural geology and prerequisite geology courses versus raw scores on *Space Relations* test. Grade-point averages calculated on basis of A = 5, B = 4, etc.

The correlation is better for petroleum engineering majors (Fig. 4, B) than it is for geology majors (Fig. 4, A). The scatter demonstrated for geology majors is primarily due to students with low raw scores on the *Space Relations* test and relatively high grade averages. This tends to flatten the line of concentration and thus lower the correlation coefficient. Part of the spread can be accounted for by the student who consistently rides the borderline between letter grades and thus ends up with a grade point average that is not truly indicative of his ability. The incentive factor satisfactorily explains this relationship also. The petroleum engineering majors as a group tend to rely more on their native ability and thus reflect a better correlation between their grade averages and the test results; the geologists give more effort to the courses, rise above their innate and background ability, and show less correlation between grade averages and test results.

The results of these tests over three years have given us insight that is useful both in understanding, and in helping to solve, the students' problems in structural geology. These students probably had similar problems in mineralogy, particularly in the part devoted to crystallography. By demonstrating the positive correlation of Figure 4 we have established the students' need for ability to visualize throughout the basic geology program.

As a result we suggest this test be given to each geology major at the outset of his geology course program. This will help to predict the visualization problems he may anticipate in his course work, which in turn reflect his chances of successfully obtaining a degree in geology. Visualization ability probably can be developed, and may be aided by requiring courses in descriptive geometry, solid geometry, or even art.

By locating the potential "A" and "B" student early in his career, we should expect to be pinpointing the majority of those of graduate capabilities. Although many of these students have not yet graduated, of the 16 that have entered graduate schools in geology, 11 had scores of 78 or higher. One of those below 78 entered graduate school in geology but has since transferred to law school. This leaves 11 of 15 currently in graduate school in geology who scored 78 or better on the *Space Relations* test. By coincidence, this is the mean score for those receiving a "B" in structural geology.

CONCLUSIONS

1. Students who score 80 or better on the *Space Relations* test have favorable odds to get an "A" or "B" in both mineralogy and structural geology; those who score below 65 have only 1 to 6 odds of getting an "A" or "B" in either mineralogy or structural geology.

2. A positive correlation exists between raw-score performance on the test and letter-grade average in structural geology and all prerequisite geology courses. Thus it is advantageous to administer this test as early as possible in a geology student's program in order to include courses to improve visualization if he is deficient in this ability.

3. This test should be an aid to pointing out the potential graduate student in geology as demonstrated by the high odds of getting good grades. Our small sample of 16 students who have so far entered graduate school includes 11 who scored over 78 in the *Space Relations* test.

ACKNOWLEDGMENTS

E. L. Lundelius, Jr., gave helpful suggestions on the statistical control of these data. P. S. Clabaugh critically read the manuscript. The help of each is gratefully acknowledged.

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A SIMPLIFIED SLIDE RULE FOR STRATIGRAPHIC SECTION MEASUREMENT

RICHARD L. THREET
*University of Utah**

ABSTRACT. To encourage rapid and convenient stratigraphic computations in the field, where mistakes can be detected and corrected most easily, a simplified, expendable, circular slide rule is presented for the popular Brunton-and-tape and other sine-based methods. Scale design and subdivisions are kept simple to the point of compatibility with realistic precision of field measurements, to avoid clutter and confusion. The author will send copies of the computer, printed on heavy cardboard stock, to any correspondent who requests them.

The Brunton-and-tape method seems to be an overwhelming favorite for stratigraphic measurement (Robinson, 1959), although Jacob staffing and other methods sometimes offer greater advantages. Unless the strata are essentially perpendicular to the topographic slope and are traversed in a strike-normal direction, rather elaborate trigonometric computations must be made by utilizing taped slope distance, angle of slope, angle of dip, and azimuth of traverse. The well-known textbook on structural geology by Billings gives a graph which simplifies the thickness determinations.

If the traverse is strike-normal, the trigonometric computations are comparatively simple, according to the following formula:

$$T = D \sin (\theta \pm \alpha)$$

where T is stratigraphic thickness, D is slope distance measured in a direction at right angles to the strike, θ is angle of dip, and α is angle of topographic slope where the traversed interval crops out. The sum of θ and α is used if the strata dip opposite the direction of topographic slope; the difference is used if the strata dip in the direction of slope, but at a greater angle than the slope.

The additional effort sometimes required to run a strike-normal traverse usually is justified by the resulting simplified computations and by reduction of the number of required instrumental readings and associated *errors* (not to be confused with mistakes).

Many geologists prefer to record only angle and distance measurements in the field, leaving the computations until evening or other office time. This false economy of field time does not permit recognition of *mistakes* (not to be confused with errors), which could have been sensed and eliminated more readily if the computations had been done in the field and roughly checked against independent estimates. *Computations should be done in the field!*

* Present address: Department of Geology, San Diego State College, San Diego, California.

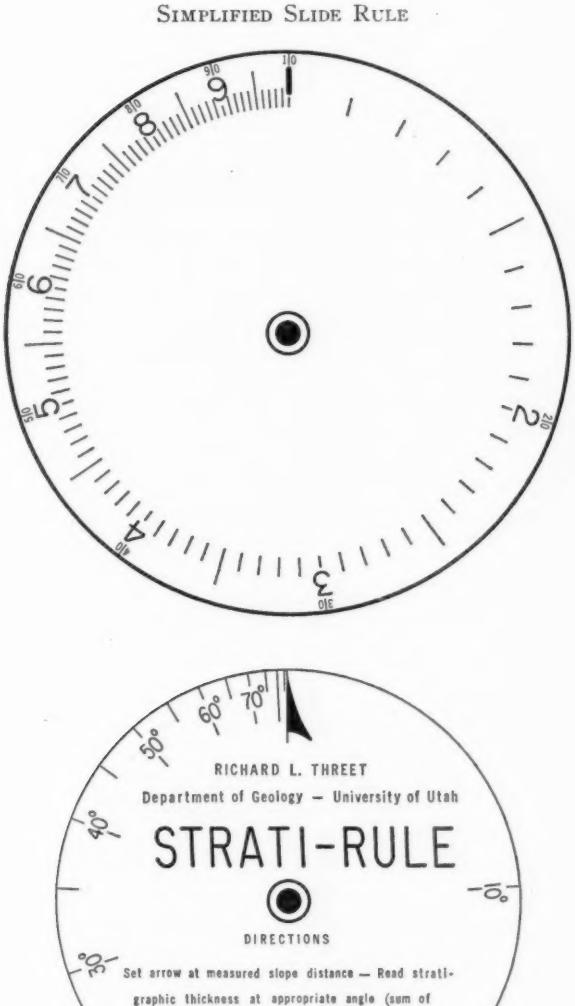
RICHARD L. THREET
Department of Geology — University of Utah
STRATI-RULE
DIRECTIONS
Set arrow at measured slope distance — Read stratigraphic thickness at appropriate angle (sum of dip and slope angles, if dip opposes slope; difference, if both in same direction)

FIG. 1. Dials of simplified stratigraphic computer. The smaller dial is fastened concentrically over the larger one, either with a thumb tack or with a dressmaker's eyelet from the notions counter of a department store.

The author will gladly send one assembled computer and a limited number of unassembled computers, printed on heavy cardboard stock, to any correspondents requesting them.

Although the simple strike-normal computations can be done rather easily with an ordinary slide rule, few geologists would carry an expensive or bulky slide

rule into the field. Strange as it may seem to those who appreciate the convenience of a slide rule, many geology students have never learned to use one confidently, especially for trigonometric computations, because of the apparent complexity of the non-linear and variable scale subdivision, "folded" scales, and decimal parts of degrees. Accordingly, the simplified STRATI-RULE illustrated in this short paper overcomes the imagined difficulties of stratigraphic slide-rule computations in the field. (1) The STRATI-RULE is an expendable but durable computer, printed on heavy cardboard and assembled with an ordinary dressmaker's eyelet, small enough to fit conveniently into a shirt pocket or inside the cover of a field notebook. (2) The single-cycle decimal scale ("C" or "D" scale of an ordinary slide rule) for stratigraphic thickness has been designed in endless circular form to avoid "running out of scale" or the necessity for a "folded" scale familiar to users of conventional straight slide rules. (3) The single-cycle angle scale (sines of larger angles or "S" scale of an ordinary slide rule) for dip and slope angles has been graduated only at 5° intervals, from 10° to 90°, to avoid the confused crowding of scale graduations for large angles or a varying of values of subdivisions from smaller to larger angles. Dip and slope angles can be interpolated easily to the nearest degree; any further refinement in measurement or interpolation would be meaningless in most stratigraphic work. The STRATI-RULE is not intended for "three places beyond the decimal point" engineers; it is intended for realistic field geologists, who know that most reported stratigraphic thicknesses with more than two significant figures are generally deceitful and indefensible.

Lest there be some misunderstanding about the precision (not to be confused with accuracy) of the thickness computations with this computer, let it be stated that the precision, or degree of refinement in interpolation of values on the scales, is comparable to the over-all precision of measurements in the Brunton-and-tape method. While the taped distance may be reliable to three or more significant figures, the slope and dip angles in rough terrain and inherently irregular stratigraphic and structural surfaces are seldom as good as two significant figures. Thus, the *accuracy* of the computed stratigraphic thickness, or degree of agreement with the true stratigraphic thickness, probably is meaningless beyond the second significant figure, even if the computations are done with ten-place logarithms. No consideration has even been given to the inevitable positive error of a few per cent or more, owing to the virtual impossibility of determining and maintaining the exact direction of an intended strike-normal traverse. The accuracy of the measurements can be checked, statistically, only in terms of the reproducibility of repeated measurements over the same stratigraphic interval; most stratigraphic field work will not permit such extravagance of time, relying instead on independent estimates or approximations to detect blunders or gross mistakes.

The accuracy of the computations (not of the field measurements) with the STRATI-RULE computer depends on accuracy of positioning of scale graduations and concentric assembly of dials of the computer; the error in a properly assembled computer is far below the inherent errors in even the most carefully executed Brunton-and-tape traverse across the most highly regular strata and structural attitudes found in the field.

Although the STRATI-RULE was designed primarily for use with strike-normal Brunton-and-tape traverses in dipping strata, it can be adapted easily to several other stratigraphic measurements. In the special case of flat-lying beds, the dip is *zero* and the stratigraphic thickness is read opposite the slope angle alone. Of course, this "stratigraphic thickness" is also the same as the difference in elevation between the two ends of the tape (or between the two stations separated by a paced slope distance in a pace-and-compass traverse), so the STRATI-RULE can be used also for vertical-distance computations.

In the Hewett method of clinometer measurement of dipping strata (Lahee, 1952, pp. 430-431), the stratigraphic interval or thickness spanned by each "step" is found by setting the index arrow on the inner dial of the STRATI-RULE at the individual's "height of eye" on the outer dial and reading the corresponding thickness at the *complement* of the angle of dip at which the clinometer is set.

Inasmuch as the inner dial of the computer is based on sine functions of angles (or cosines of complements), the computer can be adapted to many other sine-based (or cosine-based) computations.

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GEOLOGISTS VERSUS THE FOREIGN LITERATURE*

DOROTHY B. VITALIANO
U.S. Geological Survey, Bloomington, Indiana

ABSTRACT. For reasons of cost, time, and accuracy, it would be desirable for geologists to be able to read foreign literature in the original language rather than depend entirely on translations, but in spite of language requirements for advanced degrees few at present ever attain adequate proficiency to do so. Language requirements would acquire real significance if students were encouraged to study languages as early as possible and then to make it a habit to use them in connection with geology courses. It is up to geology teachers to devise means of implanting that habit.

An astronomer friend once remarked, "Why should I bother to learn Russian? If I want to know what's in a paper, I'd rather pay a translator to bat out a translation for me."

I don't know exactly what the situation may be in astronomy—though I'd be willing to wager it is no different from that in the earth sciences—but I can give several good reasons why geologists and geophysicists should not depend entirely on translations, in Russian or any other language.

The first reason is fairly obvious: the translator must be paid. A few large companies or institutions may be able to support staffs to search the literature and keep their research personnel suppled with abstracts, summaries, or full translations of papers pertinent to their work, but even for these there must be a limit to how much material can be translated. For most geologists surely the cost is a very effective barrier to much of the foreign literature. The number of books and periodicals that are now being translated, particularly from the Russian, is increasing rapidly, but it still forms only a small percentage of the total volume of material being published—and these translations are seldom, if ever, cheap.

The second reason can be very important in a race for scientific supremacy: translating takes time. Even if a geologist becomes aware of a particular book or paper just as soon as it is available in this country, and even if the money to pay for translation is forthcoming, it will take somebody a certain amount of time to prepare a translation for him; just how long depends on such factors as the length of the work and the skill and availability of the translator.

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If the geologist can't at least read the title in the original language, it will make no difference how promptly he receives the foreign publication; he will have to wait until someone else—perhaps an abstract journal—draws his attention to it, or until a translation is published, before he can even learn whether or not the work is of interest to him. But it takes a minimum of weeks, sometimes months, and occasionally years, for an abstract to get into print; thus far, the cover-to-cover translations of journals have been appearing a good year later than the originals.

The possible consequences of such a time lag are aptly illustrated by the fact that a semi-popular Russian magazine containing a full description of plans for launching an earth satellite lay for months on the shelves of our Library of Congress, unnoticed by anyone who appreciated its significance. A translation did reach such hands eventually—on the day *after* the first Sputnik took this nation by surprise.

The third, and to me the most important, reason is that any translation is second-hand information. Consider for a moment the requirements for a technical translator: "(1) He must have a fairly extensive knowledge of, and be able to reason in, the subject matter of the translation . . . (2) He must be able to read the language he is reading well enough so that he can grasp the author's intended meaning, even if poorly expressed. (3) He must himself be able to embody that meaning in lucid and straightforward English" (Fischbach, 1953, p. 388). The ideal translator of geologic material, therefore, would be a well-trained geologist who is bilingual.

Thanks to our long pre-Sputnik tradition of neglecting foreign languages in the schools, the main source of translators in English-speaking countries has been émigrés, who may fall short of the ideal in technical training or command of English or both. Even when a foreign-born translator has the technical background, he faces the task of writing in a language not his own. The result is that "in almost any technical translation into English there will be found a certain residue of foreign words, foreign senses of words, foreign ways of putting things, all requiring to be at least mentally anglicized by the ultimate reader, if not by an intervening editor, before communication with the original writer can be established" (Van Haagen, 1955, p. 123). This is often apparent in papers published in English in foreign journals, and even more so in some of the English summaries accompanying papers written in other languages. In extreme cases, the meaning may be clear only to a reader who is acquainted with the writer's native language.

On the other hand, even if the translator is completely bilingual, he will still be at a loss when it comes to rendering into the proper jargon something he doesn't understand at all in either language. An American-born professor of French once told me that the most difficult translation he ever attempted was putting into French the directions for knitting Argyll socks.

Of the three requirements for a translator, technical background is without doubt the most important;[1] but well-trained geologists, whatever their mother tongue, naturally prefer to work as geologists if at all possible, especially as there is no great financial inducement in translating as a career. Translation services therefore have to take the best they can of a limited choice, and are fortunate when they can find translators who have more than a bachelor's degree in the subject. As a result, they must rely on technical editors to prevent serious mistakes. It is even more difficult to find individuals who are both qualified and available for this type of editing, and they of course not only add to the cost and to the time lag, but also interpose still another mind between those of the author and the ultimate reader.

In view of all these factors it is not surprising that the quality of translations now appearing is very uneven. Some are excellent, most are passable, and some are misleading or even positively erroneous—sometimes all within the covers of a single issue of a journal. For example, in one paper on the internal constitution of the earth the Russian word "kora" (crust) was consistently translated as "core" (Levin, 1957). A more common type of mistake is too-literal translation, such as the rendering of "kamennyy ugol'" as "stony coal" (Matveev and Martynov, 1958). When I asked several geologists what "stony coal" meant to them, their answers ranged from "anthracite or hard coal" (which is essentially the definition found under "stone coal" in the AGI glossary) to "impure coal or carbonaceous shale"; not even a coal specialist realized that it meant "bituminous coal" until it was presented in the context of the sequence "brown coal—stony coal—anthracite." An extreme example of what can happen—and this one didn't get into print because even a non-geologist editor could see that something was wrong, though he didn't know what—was the classic case where, in a paper on coal formations, the Russian for "barren strata" was translated "unpregnant beds".

All in all, the geologist who can read a particular foreign language not only saves money and time but also communicates directly with the author, in contrast to the one who relies on translated material. That he has an advantage over the one who doesn't use the foreign literature at all is implicit in the fact that a reading knowledge of one or more foreign languages has long been a requirement for advanced degrees, and in special cases even for the bachelor's degree.

In discussing the matter with many geologists, including a large proportion of teachers, I have found that very few ever developed a reading skill beyond the stage of slow, painstaking mental translation which quite effectively discouraged further use. This undoubtedly stems from the general tendency of students to regard the language requirement as an obstacle to be overcome with the least

[1] In an earlier paper (Vitaliano, 1959) the writer endeavored to show that, given the geologic background, a knowledge adequate for reading geologic papers can be acquired without extensive study of a language. This is well corroborated by the fact that one of the most readable, accurate, and inexpensive cover-to-cover translations of a Russian journal now available is being put out by an American geologist who taught himself to read Russian but does not speak it.

possible expenditure of effort. Too often the examination is passed by cramming, after which the language is quickly forgotten. The reactions of those who do not now use the languages they once had to learn range from regret to indifference to actual antipathy for the foreign literature. The somewhat cynical title of this paper was prompted by the dishearteningly large number who seem to belong in the latter category; I hope my sampling has not been truly representative.

It appears, therefore, that the present methods of meeting the language requirements are not accomplishing the purpose of those requirements, resulting in a tragic waste of time both for the student and for those who prepare him. It is all the more tragic because it would take only a little more effort to bring the student to the stage where he can read geologic literature without mentally translating and without resorting to the dictionary too frequently. Once the fundamentals of grammar and syntax have been learned (in a first-year college course or the equivalent), reading fluency is mainly a matter of vocabulary; this comes only with practice. The purely geologic vocabulary in a language cannot be learned in any language course, not even one designed for scientists in general; it can be acquired only by reading geologic works in that language. Words and expressions that are encountered repeatedly will gradually become part of a permanent working vocabulary, in contrast to those learned by cramming.

I believe wholeheartedly that the language requirements could have lasting significance if teachers of geology would promote use of the foreign literature by their students, the earlier the better. Human nature being as it is, probably the best way would be to require its use in conjunction with geology courses. The exact ways of achieving this should be worked out to suit the foreign language resources of the student and teacher and of their department as a whole.

Those students who have learned to use one or more languages in connection with their course work or research projects will enter the profession prepared to continue using the foreign literature as needed. Not only will they benefit as individuals, but the profession as a whole could not fail to gain if there were a larger supply of well-qualified potential translators and technical editors. The individual who becomes proficient in a Romance, a Germanic, and a Slavic language will find a very large proportion of the world's geologic literature at his command. Until every geologist can be so equipped, however, there will be a need for translations.

Before dismissing as unrealistic the thought that the day might ever come when every American geologist—or every American scientist for that matter—will have a working knowledge of three other languages, remember that Europeans have long achieved it without undue agony. Admittedly, they are favored by geographic factors, which we cannot duplicate, and by educational factors, which we can. The trend toward teaching languages in elementary schools here is beginning and should be encouraged; future generations of students may be equipped to communicate with foreign scientists through the spoken as well as the written word, and however small such a contribution to international understanding may be, it could not fail to be a positive one.

The immediate problem, however, is to stimulate today's students, who have not been thoroughly exposed to foreign languages, to use the foreign literature. From this very limited point of view the ability to *speak* the language fluently is irrelevant, no matter how desirable it may be for other purposes.

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TEACHING ALPINE STRUCTURAL GEOLOGY IN FRENCH

ALBERT V. CAROZZI
University of Illinois

ABSTRACT. The graduate course in alpine tectonics given in the fall of 1959-1960 at the University of Illinois, designed to provide specialized training in structural geology, was also utilized to give experience in discussing geology in French. Lecturing was carried on in two languages for six weeks; gradually the English was reduced and finally was dropped almost entirely. Most students took their notes chiefly in English, with side notes in French, or conversely when their knowledge of French was sufficient. Each student read widely in the French literature of the Alps, and presented two written reports. A final examination tested the students' ability to analyze contrasting hypotheses presented in a lengthy French essay which they had not seen previously. The course was successful and will be repeated in alternate years.

Ignorance of foreign languages, particularly French and German, remains a point of great weakness in the training of our graduate students in geology.

The effects of such a situation are clearly displayed in the geological literature by the repetition of discoveries, bibliographical misquotations, and distortions of all kinds which delay the progress of our science. Russian has not been mentioned because it is becoming the most-translated foreign language. To what extent the translations are reliable is a question on which I am no judge; in any case we remain confronted with the problems of German and French.

It is obvious that the best translation will never replace the direct reading of the original. A well-trained geology student should be able to read such German and French classics in structural geology as Stille, Kober, Von Bubnoff, Staub, Kraus, Goguel, Argand, Lugeon, Gignoux and Moret during his years of graduate study. The required reading and translation examinations for the Ph.D. which are standard in most of the universities of this country are really a test of translation capacity—I would say of temporary translation capacity—and nothing else. In my opinion, these examinations come much too late in the curriculum, because a student should be able to read a foreign language well before the doctorate level to get most of the profit out of it. Really the problem should be taken care of, as in Europe, at the high-school level.

These Ph.D. examinations, moreover, by their very nature treat the subject as a dead language, and appear often to be an end in themselves and just another obstacle to overcome on the way to the degree. They do not correspond to an

assimilation of the language, not even of its technical terminology, because they are not integrated with the rest of the curriculum.

What a graduate student needs is precisely such an integration, represented, for instance, by being exposed to spoken scientific French, in order to add to his translation ability the capability of understanding a foreign geologist or of participating in a discussion at an international congress.

It was with this idea in mind that, in the fall semester of 1959-60, I tried at the University of Illinois the experience of teaching a graduate course in alpine tectonics in French. The course was designed to provide first of all a specialized training in structural geology and second to offer a possibility to the students to hear spoken French and discuss geology in French. The class consisted of ten graduate students who had already passed the Ph.D. French reading examination. It met twice a week, for a total time of about 30 hours. All students were taking the course for credit, and no auditors were admitted in order to keep the class down to a small efficient group.

The technical terminology naturally was the first major obstacle. It was overcome in two ways. The first was by putting strong emphasis on visual aids, such as structural cross-sections drawn on the blackboard, geological and tectonic maps, and color slides. The second was by the previous preparation and distribution of a European stratigraphical column, and of an informal French-English vocabulary in alpine geology. This list of about 600 technical terms appeared to be very useful to the students, who always faced the problem of choosing in dictionaries what could be the geological sense among several given for a certain word. In such a choice, the chances are great of not picking up the correct geological meaning of a word.

Here are some examples taken from translations completed during the course:

Terrain:	translated as piece of ground, ground, soil, earth, position, site, field instead of *geological formation.*
Niveau:	translated as level, standard, horizontal instead of *bed* or *stratum.*
Gouffre:	translated as gulf, abyss, whirlpool, pit instead of *sinkhole.*
Décrochement:	translated as action of unhooking, disconnection instead of *tear-fault.*
Eaux de fonte:	translated as smelting, iron, cast-iron, iron-bearing waters instead of *melting waters.*
Actuel:	translated as actual, real, effective instead of *of the present time.*
Hauts-fonds:	translated as thick deposits, great depth instead of *shoals.*
Classement:	translated as stratification instead of *sorting.*

Se coucher:	translated as lying flat instead of *becoming recumbent.*
Se laminer:	translated as to flatten instead of *crushed tectonically.*
Sillon:	translated as furrow, groove, gouge instead of *valley* or *canyon.*

At the beginning, the lectures were given in two languages. Each sentence was first spoken slowly in French, the main words being written on the board and translated one by one, and finally the whole sentence was repeated and translated into English. This method of teaching was carried on during six weeks, until most of the technical vocabulary had been assimilated. It corresponded in the course to the nomenclature of structures, the principles of the analysis of tectonic maps, and a discussion of sedimentation and stratigraphy from the beginning of the alpine cycle in the Triassic to the Tertiary orogenic phases.

This introduction took care of almost the entire technical terminology for the rest of the course, and at the same time provided a bridge between the previous knowledge of the students and the new field presented to them. Needless to say, these first weeks were hard on everybody, particularly on the instructor, whose main defect was to lecture too fast. Gradually the situation eased, and the emphasis could be shifted from terminology and syntax to geological discussion.

The English translation was first reduced to short summaries of several French sentences, then to abstracts of paragraphs. Finally, lecturing was given almost entirely in French with the exception of short comments in English wherever special clarification was required. After the introduction on terminology and stratigraphy, the course dealt with the structures of the foreland, the two geosynclinal troughs, the median mass, and the hinterland.

The reaction of the students varied considerably and was a function of their personal knowledge of French. Most of them, after several attempts at French, took their notes in English, with side notes in French intercalated in the text or written in a second column. Others, whose knowledge of French was sufficient, took their notes in that language with side notes in English; and some created a hybrid language which could be understood by themselves only.

Each student had to choose from a list of papers dealing with alpine geology two works of his particular interest to be translated into English and turned in before the end of the semester. These translations were analyzed in detail with the instructor during personal meetings. Unfortunately, lack of time prevented a discussion or presentation of them to the class.

Credit was given after completion of the two translations and a three-hour final examination. The latter consisted of a lengthy essay on alpine tectonics written in French, in which were hidden numerous erroneous structural and stratigraphic statements. The first assignment was a direct translation into English, and the second was the correction of the erroneous statements and the restoration of the right geological significance. Dictionaries were allowed during the final examination.

The semester results were very encouraging; half of the class was in the A range and the other half in the B range. From a teaching point of view, the adopted method worked out well and the course was a fascinating and challenging experience, though quite hard to conduct in its initial phases because of the difficulties in terminology and the lack of previous experience in such bilingual lecturing.

From a student point of view, the course was considered extremely profitable after the initial hardships had been forgotten. It was interesting to notice that, after about four weeks, the students requested the gradual dropping of English, which in their own words was confusing them. This happened much earlier than had been anticipated by the instructor. The course will be repeated every other year and modified according to the results already obtained.

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THE GEOLOGY MAJOR IN A SMALL COLLEGE

OLCOTT GATES
The Johns Hopkins University

ABSTRACT. The normal geology major of 24 to 30 semester hours in the small liberal-arts college is not adequate preparation for graduate study. For many students the price of their liberal education is an extra semester of graduate school if they are to compete equally with graduate students who have had more undergraduate geology courses in a large university. The small department cannot offer more courses; but it might be able to integrate its courses, and by doing so present more material at a more advanced level in the same length of time. Integration of the following courses into 3 one-year units is suggested: (1) crystallography, optical crystallography, mineralogy, and petrography; (2) sedimentation, paleontology, and stratigraphy; (3) structural, field, and regional geology.

In 1950 a joint committee of the Geological Society of America, the Association of Geology Teachers, and the American Geological Institute discussed the role of the geology department in the small liberal-arts college. The committee recommended that the geology major be tailored to a liberal-arts program and that its primary function "should continue to be that of preparing students for postgraduate study" (1950, p. 12). The excellent teaching and dedication to the undergraduate found in the small college were acknowledged; and the fact was recognized that the small size of its staff limited the number of courses that could be offered. The heart of the committee's recommendation lies in the following statement (1950, p. 12): ". . . The widely accepted requirement of a minimum of 24 semester hour credits in geology is adequate, provided the courses making up this total are satisfactory as to coverage and quality of instruction, and provided also that they include certain basic courses. . . Far better to offer only the bare number of courses necessary to provide this total, with unremitting effort to make each course as effective as possible, than to spread the departmental offerings thin. . ." The basic geology courses specifically recommended by the committee actually totalled closer to 30 semester hours than 24. The committee also emphasized the importance of including in the geology major an almost equal number of courses in basic allied sciences such as chemistry, physics, and mathematics.

Most small colleges concentrate on the liberal-arts approach to education, take pride in the students they place in graduate school, and require 24 to 30 semester hours each of geology and allied sciences. On paper the committee's program appears realistic, but evidently their report did not settle the matter. The operation of a geology department in a small college has been repeatedly discussed in the *Journal of Geological Education* since the publication of volume 1, number 1 in 1951.

I think that the committee's recommendations are in fact unrealistic. An undergraduate program of 24 to 30 hours may be enough geology to place a good student in graduate school, but it is no longer adequate preparation for graduate study itself. Preparation for admission and preparation for graduate work are not the same thing. Most graduate schools choose their students on the basis of undergraduate grades, the graduate record examination ability scores, and faculty recommendations, not on the number of geology courses taken. They feel that once they have corralled a bright student, they can teach him all the geology he needs for undertaking the Ph.D. program. And these needs in many graduate schools amount to more than 24 to 30 hours of the normal undergraduate courses in geology. (We are not concerned here with the equally important need for allied sciences). The student from a liberal-arts college must commonly take extra courses his first year in graduate school, in order to acquire an equal footing with fellow students who have had more than the minimum number of courses in their undergraduate careers. An extra semester of graduate work is the price many students must pay for their liberal education. The demand for a true liberal education in these troubled times is so compelling that a student who responds to this demand should not be required to pay an extra price. The problem is to provide a realistic preparation for graduate study within the framework of a liberal education.

The normal program of 24 to 30 hours of standard geology courses is no longer adequate because modern research has multiplied, at an almost exponential rate, the knowledge a student is expected to master. Not long ago, a student who knew the main elements of symmetry, who could recognize and name the crystal forms, system, class, and twin laws, and who could draw a crystal accurately from goniometer measurements was adequately prepared in crystallography. Today he should know point-group symmetry, space groups, and lattice theory. In mineralogy, a thorough knowledge of the classification, physical properties, chemical composition, and general occurrence of minerals is not enough. He must understand their structure, their crystal chemistry, and their phase relations. Petrofabrics and the deformation of rocks in the laboratory have become important fields in structural geology. These examples could be multiplied in every discipline of geological endeavor.

Large departments meet this rising exponential curve of geological knowledge only partly by emphasizing new techniques and concepts within existing courses. They also expand their staffs and add new courses. The student in a large department where a wide variety of courses is available usually takes considerably more than 24 to 30 hours of undergraduate geology before he is confident of his preparation for graduate study. I teach undergraduates in a department of moderate size at a university dedicated primarily to graduate education. Our basic and minimum program for the Bachelor's degree in geology—about 30 semester hours of geology courses generally considered fundamental—is not essentially different from that proposed by the committee. Our undergraduates are in constant contact with graduate students and are well acquainted with the demands made of them. Without exception, undergraduates bound for graduate school insist on taking

at least 40 semester hours of geology. My plea—as undergraduate advisor—that the world needs most of all widely informed citizens goes unheeded. These students know that if they do not take these extra courses, even though they may be admitted to a good graduate school, they will have to take them there and thus increase time and expense to the Ph.D. For example, at Johns Hopkins we require for admission to graduate school the same minimum program we require for the Bachelor's degree. But any graduate student who studies here must be adept in the use of a petrographic microscope. Those students who already have had this training in college have a distinct advantage. Although lack of training in the microscope is not a deficiency for entrance to the graduate school, it is in fact a deficiency for graduate study.

Many small colleges have done well in upgrading the content of their courses and pruning them of outdated techniques and concepts; and they teach these courses very well, on the whole probably better than does a large university. But they cannot offer the extra courses available to an undergraduate in a large department. They must stay within the framework of a liberal education—to which I firmly subscribe—and they do not have a large enough staff to offer many courses without "spreading the departmental offerings thin." The only recourse open to the small department is somehow to find the time to teach more material at a more advanced level within a strictly limited number of courses. The following suggested solution is experimental and perhaps radical, but it may be worth a try.

The large department in a university operates under a number of handicaps in providing maximum education for the undergraduate. The undergraduate does not have the undivided attention of a staff which has responsibilities also to the graduate student and to research. Large classes further dilute this attention, and much of the teaching may be done by inexperienced graduate students. Finally, the courses are commonly highly compartmentalized according to the interest and specialty of the professor. One man may teach crystallography, another mineralogy, a third petrography, and so on. The result is a considerable waste of time in overlap and repetition of material. In my own teaching, perhaps one-quarter to one-third of my time is spent reviewing and emphasizing subject matter in another man's course which is particularly applicable to mine and in briefly summarizing material yet to be given in other courses. Scheduling conflicts may compound this waste by upsetting the logical sequence in which the student should take his courses.

The small college offers exclusive dedication to the undergraduate, more personal contact between student and professor, and emphasis on good teaching, all of which are clearly advantageous for effective education. Yet in the search for more time to present more material, the small department may have another unique and inherent advantage, which stems paradoxically from its very smallness. In such a department one professor usually teaches several subjects. This permits elimination of repetition and overlap by integration of courses to a degree not possible where different courses are taught by different professors. The large departments are stuck with a separate-but-equal organization of courses. The

small department may be able to integrate its basic courses, and by so doing cover the same ground in less time and upgrade course content significantly.

The following ideas on how integrating and upgrading might work assume a department having a minimum staff of two men. It is further assumed that their teaching load must not exceed two courses of three classes and one laboratory per week in order to provide time for keeping up with the literature and carrying on enough research to maintain interest, enthusiasm and a realistic point of view towards geology.

Crystallography, optical crystallography, mineralogy, and petrography are commonly taught as separate subjects in that order. These might well be integrated into a single one-year course. The first part would be devoted to the interdependent fields of crystallography and optics. With this background, minerals could be studied in hand specimen and in thin section as they are found in the rocks themselves. Take granite as an example. In studying the feldspars, the student learns triclinic crystallography and optics, the relations between these and twinning and cleavage, exsolution as illustrated by perthites, and the textural relations of feldspars to other minerals as a clue to processes of crystallization. The quartz provides an opportunity to study uniaxial optics; and the biotite serves as an example of the crystallography, optics, and petrographic relations of typical micas. The student is not only studying the separate minerals, he is also learning about granite as an entity in itself. Skill with a hand-lens comes much more rapidly if used in conjunction with the much larger magnification of the microscope. Perthite naturally leads to class discussion and reading on exsolution and the alkali feldspar system; and zoning in the plagioclases does the same for a typical solid-solution system and the problem of equilibrium. A month or six weeks spent on milking a granite dry might teach more about the basic principles of crystallography, optics, mineralogy, and petrography, and—perhaps most important of all—about the actual approach used in geological research, than twice the time spent on the same subjects spread over four courses. A study of rhyolite flows and tuffs raises problems concerning the differences in textures and mineralogy between intrusive and extrusive rocks. Work on gabbro and basalt gives practice in applying these basic principles and techniques to another suite of minerals and textures and also shows the significance of differences in composition of magmas. Concentration on an alkalic rock brings still other types of minerals, textures, and problems. The same approach could be used in the study of metamorphic rocks. Metamorphism of basaltic rocks to a greenschist, then an amphibolite, and finally a pyroxene granulite, is a logical sequence of study. Sedimentary rocks might be left to the next integrated unit.

This seems like a tall order for one year; but the emphasis is on the processes of geology—how nature functions—and on the research skills used in discovering those processes, rather than on the results. The student would not learn a multitude of mineral and rock names, or to recognize every fairly common mineral (he would learn the most common), or all the arguments for and against the magmatic origin of granite. These can be looked up almost as easily as looking up a word in the

dictionary. He learns the basic principles, the basic skills, and the critical judgment necesary for successful scientific research.

Sedimentary rocks, paleontology, and stratigraphy are another group of courses which might lend themselves readily to integration into a single one-year course. Beyond purely descriptive paleontology, the fossil record can only be understood within a framework of sedimentation and stratigraphy; and the same could be said of each of the three with respect to the other two. The study of sedimentary rocks would employ both hand-lens and microscope.

A third unit might consist of an integrated course in structural and field geology, including geologic mapping techniques, the reading of geologic maps, and the study of regional geologic relations. No student can understand a geologic map without knowing the uncertainties involved in geologic mapping itself, and the basic data of nearly all structural geology are provided by the geologic map, whether on an inch-to-the-foot or an inch-to-10-miles scale. Ideally, this course should include a healthy dose of field work, either during the school year or during a summer. Field geology, the study of geologic maps, and the synthesis of regional geological relations all draw on the experience of the other two integrated courses. This one-year unit is thus the logical one for the senior year.

Absent from the subjects included in the proposed integration are geomorphology, oil geology, economic geology, engineering geology, and groundwater, some of which are recommended in the committee's list (1950, p. 15). I believe that if the integrated courses are mastered to the point where the student can handle modern investigative techniques and can read the literature, he is prepared to carry on beyond the textbooks in any of these omitted fields, which essentially are derivative ones. Knowledge in depth of the parent disciplines of geology should confer ability to acquire mastery of any field. However, the courses included in this integrated program must also depend on the interests and training of the staff. My program assumes a "hard rock" geologist and a "soft rock" one interested in preparing a student primarily for graduate study in "bed rock." Other departments may emphasize geomorphology and surficial geology, or paleontology. Nevertheless, it seems to me that progress in these fields requires at least a minimum knowledge of the subjects I have included. It is primarily a matter of relative weight.

These three one-year integrated units—carefully organized, pruned of chaff, and well taught—might carry the undergraduate to a level of knowledge and competence fully equivalent to that made possible by the availability of more courses in the large department. A valuable extra dividend is that the student acquires some training in research and becomes aware of the need for applying an integrated approach to the solution of geologic problems if results are not to be narrowly limited in scope and application.

With the addition of general geology, the program consists of 4 one-year courses, two courses per professor in a two-man department. The geology student who took general geology in his freshman year would take one integrated unit

per year. If he started his sophomore year, the "hard rock" and "soft rock" units would logically be taken his junior year and the final unit his senior year. The entire program is equivalent to 32 semester hours at 4 credits per semester.

Some overlap between beginning geology and these three integrated units is inevitable. First-year physical and historical geology serves the liberal-arts tradition of the entire college and must be tailored to fit a variety of student purposes, interests, and abilities, not just those of the geology major. Integration of physical and historical geology into one continuous course might be worth trying, but integration of such a course into the program for the geology major is not an essential part of the proposed scheme.

It is, of course, ridiculous to claim that a 2-man department teaching a total of 32 semester hours of geology can give an undergraduate a background in factual geology equal to that of a student who took 60 hours of geology in a 10-man department. This is not necessary or desirable. Any graduate school that picks its students on the basis of the number of hours of geology taken at the sacrifice of a liberal education is not fulfilling its responsibilities as an educational institution in this frightened world. The same could be said for a prospective employer. Fortunately both are diminishing in number. The objective of this program is to prepare the undergraduate of a small college in basic knowledge and methods of research to the point where his time to the Ph.D. is no greater than that of fellow graduate students who have had two or three additional undergraduate courses in a large university. If the program were successful, an extra semester of graduate study would no longer be the price of a liberal education.

For students who do not go on to graduate school or into geology professionally, such a program of study has inherent value as a vehicle for a liberal education in conjunction with his other subjects. The significant role of science in the world today should make the study of science as valid an approach to responsible and critical citizenship as other disciplines, such as the humanities; but unfortunately this validity is commonly obscured by emphasis on the factual results of scientific research. Few history courses today still consist of learning dates; many science courses still consist of memorizing "facts." An appreciation of the methods, logic, potentialities, limitations, and intrinsic uncertainties of science should be part of every man's mental equipment. Only if he understands that science is human too, can he think and act intelligently on the issues that bedevil mankind.

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GEOLOGIC EDUCATION AND ITS INFLUENCE ON APPROACHES TO GEOLOGIC PROBLEMS*

ARTHUR F. HAGNER
University of Illinois

ABSTRACT. Students should know something about the various ways in which the interrelated phenomena of geology are currently being studied. Because of the variety and complexity of most geologic processes, no simple method of attack can be successful for all situations. Examples of the approaches being taken by several present-day research geologists are presented. Undergraduate research is suggested as being advisable to increase students' appreciation of the various ways in which geologic problems may be approached.

INTRODUCTION

The successful scientist, teacher, or student has the ability to recognize a significant problem, go right to the heart of it, and use the best method of approach in its solution. In recent years, the methods of investigation used by mineralogists and geologists have become increasingly diversified and complex. A knowledge of these methods, and of the instrumentation employed, is a necessity for the professional geologist and teacher.

Since the teacher's task is to educate students for the future, he must constantly ask himself: "Where is geology going, what will it probably be like in twenty years, what methods and techniques must the student master, where will the next advances probably come from, and are we preparing our students adequately?" Students should know something of the latest significant problems and approaches—the research being done at present on the frontiers of geology. To understand this, and to comprehend much of the current mineralogic and geologic literature, requires a knowledge of mathematics and chemistry that goes beyond the usual elementary courses in these subjects. If necessary, it is better to limit the number of geology courses than to omit background work in the related fundamental sciences.

Early in his career the student should learn something about the aims, limitations, and philosophy of science. An understanding of the structure and evolution of geologic thought and its relation to thought in other sciences and to knowledge in general will aid the student in his own approach to geologic problems. In the words of Chamberlin (1904), "an appropriate atmosphere of philosophy is as

* Adapted from a talk given at the annual meeting of the Central Section, N.A.G.T., Lawrence, Kansas, March 26, 1960.

necessary to the wholesome intellectual life of our sciences as is the earth's physical atmosphere to the life of our planet."

The student should learn that physics, chemistry, and biology furnish certain of the methods and techniques commonly used in geology, but that geology is a natural science in its own right, with specific problems and concepts, the development of which requires special abilities, background, and approaches. Since most natural phenomena are very complex, the geologist in order to understand them must consider many variables simultaneously and may even find it necessary to take into consideration the possible existence of unknown variables. There are few rigorous "laws" in geology, because the complexity and broad scope of most earth phenomena make it necessary to incorporate many and diverse variables into any geologic construct. Therefore, there is room for differences in interpretation of the geologic record, and uniformity of agreement is seldom possible. Chamberlin's remarks (1904) still apply, although perhaps to a somewhat lesser degree than when he wrote them: "That which passes under the name earth-science is not all *science* in the strict sense of the term. Not a little consists of generalizations from incomplete data, of inferences hung on chains of uncertain logic, of interpretations not beyond question, of hypotheses not fully verified and of speculation none too substantial. A part of the mass is true science, a part is philosophy, as I would use the term, a part is speculation, and a part is yet unorganized material." Most geologic theories, unlike those in the other physical sciences, cannot be verified experimentally and are not amenable to mathematical "proof." In addition, the results of many geologic processes cannot be simulated by experimental procedure.

Geologic theories rest on what Chamberlin (1904) called "the working test" and Geikie (1905) "a balance of probabilities." The geologist's explanation often is the result of making a subjective judgment or of selecting the most likely working hypothesis and revising it as more data accumulate. He must recognize these hypotheses for what they are, and, as Bubnoff (1959) has said, remember that they represent a weakness in the structure of his theories. The student should know how to formulate hypotheses, the factors on which they are based, the kinds and requirements of hypotheses, and the limitations and cautions in their use. Geologists early learn that many earth phenemena can be interpreted in more than one way and consequently they become accustomed to "living with uncertainty." The geologist must rely to a large extent on observations of phenomena seen in the field, and occasionally in part on principles arrived at speculatively, by reasoning, or, when interpreting earth history, by "predicting backward." There are, of course, striking exceptions to this generalization; much of our knowledge of crystallography, and many aspects of mineralogy and petrology, such as phase relations in igneous rocks, is based on verifiable experiments. Umbgrove (1947) has compared the geologist with the historian who reconstructs the past by using available data, and where these are incomplete, employs temporary hypothetical constructs to bridge the missing data. Since many earth phenomena cannot be verified experimentally, and commonly the geologist cannot "get at" the problem directly, it is necessary for him to use various indirect methods of analysis. He is forced to create reason-

able constructs and extend them, e.g., the principle of uniformitarianism. These methods of reasoning and "explaining" nature are necessary because the geologist deals with time and scale fatcors beyond human experience.

KINDS OF APPROACH

There are many individual approaches to mineralogic and geologic problems, but the geologist characteristically employs two principal kinds. The first is the field approach, in which a variety of techniques may be used and where gross natural phenomena are studied *in toto*. In the field the results of processes are observed as they occur in nature, and facts and relationships are discovered that are unobtainable in the laboratory. Here the geologist examines not only one mineral, rock, or small structure but studies the combined results of processes that have operated in the past to yield what is observable today. This is where the geologist must, in essence, "predict backwards." The effects of some of the earlier processes can be read in the rocks but the record is never complete, and in many instances the last process has obliterated much of the earlier history. In studying the final product the geologist has lost a parameter—that of time-dimension. The field approach has the advantage of direct observation of nature, and of seeing the whole rather than merely some of its parts.

Unfortunately, as Krumbein (1960) has pointed out, our observations are made "on products of geological processes that operated entirely beyond man's control, commonly without his presence on the scene, and under conditions in which all or most of the factors fluctuated over a wide range." In addition, "the geologist in general is limited in his observations of a phenomenon to those places (outcrops and wells) where rocks are available for examination." Therefore, there always will be an "indispensible core of qualitative observation that forms the foundation of virtually every geological study. . ."

This does not mean, however, that field observations must be indefinite or inexact. Cloud (1956) has stressed that "an orderly sequence of observations described with such precision that an objective observer, reexamining substantially the same evidence, would see substantially the same things, is the equivalent of the repeatable experiment in the empirical sciences—the recoverable observation, as it were. Just as some experiments are trivial, so some observations are trivial; and in both the experimental and the empirical sciences recoverability is never absolute. . ."

The other major category of approaches to the study of earth phenomena is that of experimentation. Experimental investigation includes several methods of analysis that have produced outstanding results and have the advantage of relative conceptual simplicity, of dealing with only a few controlled variables, and of setting limits on speculative theories derived from field interpretations. They also have limitations, since they are idealized and deal with only a few of the many variables generally present in geologic phenomena. Further, they are concluded in a short period of time, whereas in processes of nature variables may interact over a great span of time and at great temperatures and pressures; i.e., "the earth

does not behave like a small piece of rock." By isolating certain aspects of a problem for study by experimentation, we neglect "the whole" and there is a tendency to get away from reality unless the problem is also studied in other ways. Also, unless experimental results are carefully interpreted and extrapolated, they may set artificial limits on nature.

The fact that geologists generally deal with gross features that were produced over an enormous span of time, and apparently sometimes at varying intensity conditions, makes the problem of understanding natural phenomena a very difficult one. Although the formation of mountains, basins, and the crust of the earth itself is based on physical laws, there are many phenomena connected with these and other gross features of the earth "that cannot be squeezed into a formula and can only be described, and where a rule of thumb must take the place of physical deduction" (Bertalanffy, 1952). Geologists have proceeded on the basis that in geologic matters, unless well established and pertinent physical laws are violated, geologic evidence is superior to evidence of the other physical sciences. No law or theory is superior to the geologic record. "There is a validity to history apart from and independent of physics and chemistry. Even as history must unfold in nature and to that extent within the framework of natural laws, all nature must evolve in the framework of history" (Schneer, 1960). In many instances, such as the controversies in the nineteenth century over the age of the earth and the thickness and rigidity of its crust, history has shown the geologists to have been more nearly correct than the other physical scientists.

In addition to field and experimental approaches, the geologist may use thermodynamic procedures, statistical analysis, and combinations of these and other techniques. The choice of procedure is a subjective one and is determined by the nature of the problem, the techniques available or that can be developed, the training and "conceptual bias" of the investigator, and the state of development of fundamental knowledge at the time of investigation. As Bertalanffy (1952) has stated, "fundamental attitudes determine what problems the investigator is able to see; they decide the framing of his questions, his experimental procedure, the choice of method, and finally, the type of explanation and theory that are given for the phenomena investigated." Wisdom of choice is determined after the results of the investigation have been tested, by how will these "solve" the problem, and how much closer we are to "reality"—to a better understanding of nature. For an analysis of many complex geologic problems, it is necessary that within the science different individuals employ different procedures. The interdependence of approaches becomes apparent when we analyze the advantages and limitations of the different ways of investigating natural phenomena.

EXAMPLES OF THE USE OF DIFFERENT APPROACHES

The foregoing material has been presented because I have been asked to discuss the approaches to mineralogic and geologic problems used by the guest speakers at the First and Second Summer Institutes in Geology for College Teachers, held at the University of Illinois in 1957 and 1958, and sponsored by the National

Science Foundation. Since these speakers were selected, in large part, for the success and diversity of their investigations in mineralogy and geology, their researches cover a wide variety of approaches to earth problems, and illustrate the advantages and limitations of different procedures.

It should be pointed out that each speaker necessarily has his own "conceptual bias" or inclination, and that most, if not all, use it as an aid to explanation. As here used the term "bias" has no pejorative meaning, but refers to an inclination, tendency, or preference toward a view, and "conceptual bias" then refers to a mental framework within which one works and from which one reaches conclusions.

Several speakers used an experimental approach, and applied results of laboratory studies of mineral systems to geologic phenomena. Thus, Professor Frank Tuttle of Pennsylvania State University discussed the nature of residual magmatic solutions and pegmatites, and of melting and metamorphism in the earth's crust. His method of approach was based on a conceptual model wherein all igneous rocks form from melts by liquid-solid reactions. He considered metamorphism as limited to a relatively small range of conditions that take place without melting. Dr. Hatten Yoder, Jr. of the Geophysical Laboratory discussed metamorphic field phenomena such as isograds, progressive metamorphism, and the problem of metamorphism of iron-rich sediments. He also used an experimental approach, but placed more emphasis on reactions in the solid state than Tuttle did, although he too has a "conceptual bias" toward melts. Yoder believes that water content is an especially important factor in controlling the products of solid-state reactions, and he would extend the range of conditions of metamorphic phenomena beyond that of Tuttle. Professor George Kennedy, of the University of California at Los Angeles, talked about the interior of the earth from the viewpoint of an experimentalist employing high pressures and temperatures on minerals. Kennedy's "conceptual bias" is largely a sophisticated magmatic view involving pressure-dependent phenomena.

Professor James Thompson of Harvard University pointed out that actual geologic situations are much more complex than the idealized systems studied in the laboratory. The previous investigators' main emphasis was on what happened in the laboratory; they looked to the field for corroboration of results. Thompson has examined many geologic situations, and seeks laboratory corroboration. He bases his conclusions about the behavior of systems on characteristic mineral assemblages that he has observed. By a clever method of using field observations and thermodynamic reasoning, he has simplified field systems and their treatment. This approach he refers to as a petrographic one. Thompson has a "conceptual bias" toward the importance of the solid state and of metasomatism in geologic processes.

In discussing the interior of the earth, Professor Gordon J. F. MacDonald, of the University of California at Los Angeles, used thermodynamic reasoning to extend the findings of the experimental and classical geologic approaches. He described several mineral systems that had been worked out experimentally, and

showed how thermodynamic calculations and theory often can help correlate simplified laboratory studies with more complex natural conditions, place limits on the extrapolation of laboratory data, and permit generalizations that aid in understanding deep-seated phenomena. MacDonald constructed and compared models of the earth's interior on the basis of the application of mineralogic, thermodynamic, and field data. His treatment was a good example of the use of different conceptual models by one individual.

Professor George DeVore of Florida State University used a relatively simple structural-energetic type of model, into which he fit various field facts and observations. His approach to phenomena such as the formation of granite, melting, growth of crystals, distribution of minor constituents in rocks and minerals, and factors that influence the location of trace elements, was that of crystal energetics—the surface energy of solids. Many field observations and problems not well explained by experimentation could be accounted for by DeVore's model.

Other speakers discussed geologic problems from the viewpoint of low-temperature solution chemistry, clay mineralogy, the use of isotopes, and the application of statistics to the study of natural phenomena.

Contrary to Chamberlin's (1904) suggestion that the geologist employ "the method of multiple working hypotheses," most individuals used only one or two approaches to geologic problems, and then presented their results within the framework of one hypothesis or theory. This procedure probably is necessary. The history of science shows that major advances have usually not been made by employing several different approaches at one time in the study of a problem. Rather, the principal contributions have come from scientists who have stressed (and often greatly overemphasized) one idea or approach, almost to the exclusion of others. Frequently this has stimulated the development of contrasting views, and has resulted in further advances. The place for multiplicity of approach and hypothesis, for playing off one approach or hypothesis against another, is the geologic forum at large. "To use in all desirable completeness the method of multiple hypotheses, that golden principle of science, can no longer be the ambition of the individual worker. It is the job of a whole profession" (Daly, 1933).

The diversity of problems and the methods of dealing with them as illustrated by investigations of these geologists and mineralogists calls attention to a phenomenon of modern science that the teacher can do much to clarify for the student. It is what Wigner (1950) calls the shifts in science from older to new fields. Whole branches of science are sometimes given up to concentrate on new fields of interest, and this is done while old concepts are still inadequate approximations. This results in a situation in which we have huge stores of partly understood information, to which new facts and ideas are constantly being added. In each science we are left with a great need for organization, evaluation, and creative synthesis, a need that the teacher can, in part at least, fill. Wigner (1950) recognizes that the changes in interest have been "in most cases well justified inasmuch as the new subject is deeper than the abandoned one, starts from more funda-

mental realizations, and embraces the old one." He points out, however, "that the embracing of the old concept by the new discipline is somewhat illusory."

This situation has been faced by the relatively few outstanding geologists whose principal contributions to science stem from their ability to synthesize vast amounts of old and new material, and to correlate and evaluate data the significance of which had been only partly realized. Daly, Bubnoff, and others have stressed the need for large-scale synthesis in geology.

Synthesis and evaluation of the results of research in the various geologic disciplines, in an attempt to bridge the gap between them, is certainly one of the principal duties of a teacher. It is also one of the tasks we seem to fulfill least well. Synthesis of a particular subject is often well done, but synthesis of geology as a whole is less successfully achieved or is neglected. This is reflected in the many students who learn the content of separate courses but do not see the interrelationships between subjects and therefore cannot bridge the "gap" between them. This state of affairs is largely the result of the fragmentation that is today characteristic of geology as well as the other sciences, and the specialized interests of the teacher and student. Nevertheless, geologic knowledge can be integrated if teachers and students synthesize information and concepts from the different fields. Knowledge of the "connecting fabric" between old and new ideas leads to an understanding of their interrelationships and to further progress. "The parallelism between the old science and the new became so important as a guide that physicists gave it a well-defined mathematical formulation, named it the correspondence principle, and use it every day as a working tool" (Wheeler, 1956). Integration of knowledge by both teacher and student will result in a much better idea of geology, its philosophy, and the significant methods and approaches to geologic problems.

UNDERGRADUATE RESEARCH

Much of the foregoing is most effectively brought home to the student through active participation. The student learns to appreciate the applications, limitations, and advantages of the different procedures by actually engaging in research early in his career.

Many teachers have considered the pros and cons of starting research at the undergraduate level; some of their conclusions were published in 1953 and 1954 as reports of National Science Foundation conferences on research in colleges. The following discussion is based in part on the results of these conferences. Certainly there are risks in connection with undergraduate research, but these can be avoided, in large part, by careful selection of the students who are permitted to engage in research.

Those teachers who have adopted undergraduate research programs are, in the great majority of instances, enthusiastic about them—the advantages far outweigh the problems. Such research stimulates interest and develops independence of thought; it also gives the student a greater appreciation of the interrelationships

of different sciences, an opportunity to study his own science in greater depth, and experience in critical and creative thinking and reporting of results. A recent survey by Roe (1952) of top scientists from the various disciplines revealed that almost invariably they became interested in science early in their careers through a research project on which they were permitted to work independently and with little supervision.

The research project need not be large or elaborate, or require the use of expensive equipment. In fact, a small problem making use of simple, inexpensive equipment is desirable as a start. There are, however, certain common-sense requirements of any elementary project. (1) The problem should be well-circumscribed, and it should be possible to do something about it—that is, complete it in a reasonable time. (2) The problem should be challenging in the sense that it deals with things that are new. (3) The problem should be of such a nature as to permit the student to generalize—to arrive at some relationship to other phenomena. This avoids the type of research that consists merely of collecting facts. It is absolutely essential that the professor in charge be enthusiastic about the research problem and follow through with the student. Preferably, the professor should himself be doing research in the same field. We should encourage only the better students to engage in research, those with intellectual curiosity, imagination, and the ability to interpret, who will be willing to spend the long hours of routine investigation characteristic of all genuine research.

The benefits of an undergraduate research program to the faculty member and the college are also important, as they help to attract better qualified teachers and students and tend to have a beneficial effect on the general *esprit de corps* of a department. Publications resulting from research have prestige value to the college as well as to the staff member and student.

CONCLUSION

I believe that the teaching of geology, or of any science, should include more than requiring the student to learn material in a book, from lectures, and from laboratory work. The teacher's primary purpose is to stimulate the curiosity of the general liberal-arts student so that he wants to know more, and of the pre-professional student so that he aspires to synthesize and increase our knowledge of nature. It is necessary, of course, to learn facts, concepts, and techniques, and all of us insist that this be done, but preferably not as ends in themselves. But what the current problems are and how the geologist goes about solving and "explaining" natural phenomena are often omitted or left to be "covered" in graduate school. When this is done, I suspect that many potentially creative geology students lose interest and move into more challenging fields. And only too often the student in graduate school is not enlightened concerning geologic thinking and approaches, except, perhaps, in one specialized field, and his interest is further dampened when he is swamped with more material to learn.

If, early in his career, the student becomes familiar with the different mineralogic and geologic approaches, their limitations and strong points, and has an

opportunity to use some of them in his own research, he will be able to understand his science better, direct his thoughts toward significant problems, and make contributions to geology.

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REVIEWS

Studies in Paleobotany. Henry N. Andrews, Jr. xii + 487 pp., illus. John Wiley & Sons, New York and London, 1961. $11.75.

This is a *new* textbook. The organization is new, the figures are new, the writing is new—and highly readable. The book is designed for advanced botany students and for geology students who have little botanical background. Terminology has not been overstressed, and adequate definitions are given close at hand; the emphasis remains where it should be—on the nature of plants. This book should be a success from the standpoint of the teacher who recognizes the geologic importance of paleobotany, and of the student who wishes to learn about plant fossils.

The organization of this book is different from that of texts previously available. Following the introduction, in which the student is told about the geologic time scale, types of fossil-plant preservation, the classification of plants, and wood anatomy, Andrews starts with a chapter on Psilophyta and certain other early plants. Botanical classification and order of presentation adopted are modern, essentially that used previously by Bold (modified from Tippo). The twelve most advanced divisions of the plant kingdom (and three other unnamed, less definite groups) are treated in chapters. Algae and fungi are mentioned incidentally. This arrangement allows the material to be presented in about six sequences of phyletic trend, each starting with the oldest representatives and approaching the recent. The Psilophyte, Pterophyte, Pteridospermophyte, Anthophyte (angiosperm) sequence is presented most fully. This is followed by chapters on Lycopodophyta (=Microphyllophyta of Bold), Arthrophyta (calamites and horse tails), Cycadophyta, Coniferophyta and Ginkgophyta (in one chapter). A later chapter deals with bryophytic plants. Each sequence forms a unit that has coherence and moves along the time scale. A few deviations from the theme are introduced where pertinent. Heterospory and evolution of the seed habit are discussed in one chapter; another is devoted to plant-fossil evidence from high latitudes (Arctic and Antarctic). Floristic paleobotany is related to geologic occurrences in the Tertiary, in a chapter directly following that on Anthophytes; noted Paleozoic and Mesozoic floras are treated according to age and paleogeography in a later chapter. These treatments are well written and not provincial. Each chapter is introduced by a clear statement of organization and purpose. Andrews has not duplicated material from elementary texts, but he has indicated where additional background in elementary botany would be particularly helpful.

The book closes with an introduction to palynology (pollen and spore science) written by one of Andrews' former students, Charles J. Felix, and a chapter on techniques. The chapter on palynology is an innovation for a paleobotany textbook, and highly appropriate in view of the increasing practical importance of plant microfossils.

Most of the illustrations are new; many are handsomely drafted line drawings, including reconstructions not given in previous textbooks. References to classical interpretations of fossils are given, and each chapter is concluded by an ample list of references that include nearly all the original geological and paleobotanical reports on which the discussion has been based. I particularly admire Andrews' easy-reading, straightforward style. Without generalizing inaccurately, he has usually been able to avoid complications of terminology and nomenclature.

The book packs a high factual content, which is emphasized all the more by frequent references to unsolved problems. It is attractively printed, with few misspellings or misprints, and has an adequate index. I would have preferred to have a size scale directly on the illustrations, rather than stated in the text. In some instances, I would have preferred, for technical reasons, an altered wording. However, this book has been prepared as an introductory textbook and not primarily as a reference for research. Andrews' new suggestions regarding origin of the seed habit, his reference of Devonian *Sporogonites* to the mosses, and his mention of recent Russian paleobotanical work, are of interest to more advanced students, but they do not intrude on the general level of discussion.

Studies in Paleobotany is longer than other available textbooks, but its readability and related sequences will probably make it rela-

tively easy to use in a lecture and laboratory course of one semester.

JAMES M. SCHOPF
U. S. Geological Survey

History of the Earth. Bernhard Kummel. 462 illus., 23 charts, 610 pages. W. H. Freeman and Company, San Francisco, 1961. $8.75.

The end of provincialism in teaching historical geology should now be in sight. For too long we have talked of geology as the "Science of the Earth" and then in teaching historical geology we have been content to teach only about North America, the United States, or even lesser regions.

In these days of increasing world travel and "shrinking distances" it is pleasing to have in one volume such an excellent accumulation of information concerning the geology of the earth. This is important not only to geologists, but to all educated people who travel. We have all had the experience of a former student telling how much he enjoyed the Grand Canyon, or Yellowstone Park, after having had a course in geology. Now we can expect the same thing from a student who visits the Paris Basin, or southwestern Baluchistan.

This book is one of which the author and publisher can well be proud, and one which should be appealing to teachers of historical geology everywhere.

The introductory three chapters constitute a brief but clear and concise statement of the fundamentals and basic concepts of historical geology. Of particular value are the sections explaining an absolute time scale, sedimentary facies, and the sedimentary and tectonic frameworks of the continents.

In the succeeding chapters it is good to see these fundamentals followed and elaborated upon as the rocks of the various periods are described and interpreted.

The "heart of the book," in which the historical development of the various continents is described in modern concepts, is well balanced and presents an impressive amount of well-documented and well-integrated data in a very readable style.

The chapters devoted to life development are also well written and beautifully illustrated.

The 462 illustrations are presented as integral parts of the book and in no sense are they superfluous decorations or dressing.

Appendix II presents one of the most useful sets of correlation charts ever assembled between two covers.

For a teacher of historical geology who wishes to present a rigorous and non-provincial course this is an excellent text.

A. G. UNKLESBAY
University of Missouri

Structural Geology Laboratory Manual, Second Edition. John C. Ludlum and John M. Dennison. vii + 145 pp., 68 figs. West Virginia University Book Store, Morgantown, 1960. $2.95.

In his review of the first edition of this manual, Ryan (*Jour. Geol. Education,* vol. 5, no. 2, p. 34) stated that "those who would hope for a new approach in making use of the structural geology laboratory" would be disappointed because the approach was essentially traditional. It is a compliment to the authors that the second edition still follows the same format, and therefore still includes the basic, fundamental concepts of structural geology that are most essential in the beginning course. It is hard to conceive how one could hope for a structural geology laboratory manual that did not contain such important topics as structural sections, true and apparent dip, thickness and depth determinations, outcrop patterns, structural contours and stereographic projections. It is just as difficult to imagine how these could be better treated than by the use of problems that assume practical situations similar to those encountered in the field.

As compared with the first edition, this one contains an additional chapter, 23 more exercises and 21 more figures. These statistics do not, however, summarize the true worth of the book. The most attractive feature is not a new format or some new frills. The manual presents eleven basic structural geology subjects in eleven well-developed chapters, and it contains 145 exercises relating to them. By limiting the number of items presented, the authors were able to treat each with careful detail, including diagrams showing three-dimensional representations of the problems plus mathematical treatments of the diagrams.

The manual contains sets of exercises that

have been specifically designed to teach the student to think, to visualize structures in three dimensions, and thus prepare himself for his first course in field geology. These, it seems, are the most valid objectives of the laboratory and they are also the areas in which the student needs the greatest amount of assistance. The text material explains each problem in such a way that the student can understand both the theory and the mechanics of the solution. The explanations are not entertaining and sprightly, but they are laboriously precise as dictated by the very rigid requirements of tracing the positions of lines and planes in three dimensions.

Each chapter is a complete unit that contains discussions and explanations that cannot be otherwise assembled without the use of numerous references. But, most conveniently, this aspect of the manual makes it very flexible. It is not necessary to follow the same order as the chapters, inasmuch as each one is complete and does not assume knowledge of previously discussed material. Supplementary exercises can be used at any time in case an instructor's favorites are not included. In an average one-semester course, it is possible to use this manual, with a minimum of supplementation, for two or three years without repeating the same exercises. These facts, plus the authors' good intentions to make frequent revisions, allows the development of a laboratory program that does not become "stale" with the use of the same exercises in the same sequence year after year.

The maps and diagrams deserve a special note. There are 68 figures, many of which contain several drawings, that illustrate various methods and procedures. There are also many maps for illustration and for use in the solution of problems. It is becoming more and more difficult to develop original exercises based on geologic maps because of the discontinuance of the U.S.G.S. Folios. The manual discusses this problem, lists the folios that are most suitable for structural geology studies, and suggests sample exercises that can be used. Most departments, however, do not have reference materials in sufficient quantities to supply adequately a large class. The need for such materials is reduced to a minimum by the detailed treatment of each subject in the manual, and by the fact that the student retains the text material for future reference. The new edition contains an expanded reference list comprising 44 items, which refreshingly includes all major competing textbooks.

The authors state that they have designed the exercises for a structural geology course to follow immediately the first year of geology. This does not, however, seem to be an important consideration, because the work is still appropriate for courses in the third or fourth year. The laboratory studies are more effective and meaningful after the student has had trigonometry, and, if a delay is necessary for this prerequisite, it will not make any difference. The major point is to have structural geology precede the first field course.

DAVID P. STEWART
Miami University

Texas Fossils: An Amateur Collector's Handbook. William H. Matthews III. viii+123 pp., 26 figs., 49 plates. Guidebook 2, Bureau of Economic Geology, The University of Texas, Austin, 1960. $1.00 ($0.75 to bookstores ordering 25 copies or more).

Texas and the author are to be complimented for this excellent handbook designed to serve the amateur, the budding earth scientist, and the student. It is competently and entertainingly written, and nicely illustrated and printed (on slick paper)—with even a colored geologic map of Texas.

The what and why of paleontology are presented, and then information on the recognition, collection, identification, and preparation of fossils. The use of fossils, and a summary of the geologic history of Texas, complete the first part. More than half of the pages are contained in the well-illustrated section on systematic paleontology.

State agencies in other provinces might well use Matthews' pamphlet as a model.

MALCOLM P. WEISS
Ohio State University

Texas Gemstones. Elbert A. King, Jr. 42 pp., 20 figs., 6 plates. Report of Investigations 42, Bureau of Economic Geology, The University of Texas, Austin, 1961. $0.40.

This little booklet presents the art of cutting and polishing gemstones in a clear and simple way, and should increase interest in this pleasant and rewarding hobby. Clear and detailed drawings of apparatus and methods, and

simple but essentially correct explanations of the properties of minerals, should be of help to the beginner. The detailed descriptions of species are confined to Texas occurrences. The value of the booklet is increased by the inclusion of a glossary, a list of references, and six photographs of crystals and cut gems. The formulas of beryl and tourmaline are incorrectly given.

H. E. WENDEN
Department of Mineralogy
Ohio State Univesrity

ANNOUNCEMENT

Starting with Volume 10, 1962, the *Journal of Geological Education* will abandon its twice-a-year schedule and become a quarterly.

This change is believed advisable for at least three reasons. (1) It will allow the activities and functions of the National Association of Geology Teachers, especially the proceedings of the several Sections, to be reported to the membership every three months. (2) It will afford expanded opportunity for publication by the rapidly increasing membership of the Association. (3) In general, it will provide a better sense of continuity for present members and an attraction for potential new ones.

The editorial policy—namely, to print material of interest to teachers of geology—will remain unchanged. But it is hoped that contributors will address themselves less to such shopworn subjects as, for example, how to give an exam in introductory geology, and will turn toward some of the major problems that face us today. Among these are the increasing number of earth-science courses in high schools and the training of teachers to handle them adequately; the effects of crumbling science-subject frontiers on traditional instruction patterns (what price geometrics, biogeochemistry, oceanography?); and problems of expanding enrollment. Other subjects will occur to the reader. Some have already been touched on in the pages of the *Journal*, but in none has the last word, or even the next-to-last, been said.

That's enough for now. Issues will appear in March, June, September, and December. See you in the spring!

ROBERT L. BATES, *Editor*

TRANSACTIONS OF THE NATIONAL ASSOCIATION OF GEOLOGY TEACHERS

NEW ENGLAND SECTION

The annual meeting of the New England Section was held on April 14 and 15, 1961, at Wesleyan University, Middletown, Connecticut. Friday afternoon about twenty members and guests visited the recently opened feldspar mine and flotation plant of the Feldspar Corporation of America in Middletown. After dinner on campus, open house was held in the newly rebuilt geology building.

On Saturday morning, President Louise Kingsley presided over a session, attended by twenty-nine persons, which included the following papers: "The Rock Cycle," Brewster Baldwin; "New Commission on Teaching Mineralogy," C. S. Hurlbut, Jr.; "Indoor Structure Laboratory Using Sand Trays", Marshall Schalk; "The Expanded Graduate Program at Brown University", Alonzo Quinn; "Geology in the Junior High School Curriculum", Milford Deprey; and "Geology's Role in the Natural Science Course at Wesleyan", Carleton Moore.

Officers were then elected for 1961-62 (see inside back cover).

Following luncheon on campus, a second group of twenty-three visited the feldspar mine and plant.

MARSHALL SCHALK, *Secretary*

EASTERN SECTION

On Saturday, December 3, 1960, thirty-five geologists from fifteen institutions met at the Geological Survey, New York State Museum, for the *sixth annual informal meeting* of the Eastern Section, National Association of Geology Teachers.

The group met in the Seminar Room of the State Education Building Annex. A tour of the new Geological Survey offices and laboratories was followed by a guided tour of the New York State Museum. In the afternoon John Broughton, State Geologist, discussed the history of the New York State Geological Survey. Donald Fisher and Bill Isachsen discussed the new state geologic map and correlation charts, the program in geologic mapping, preparation of field trips and guidebooks for earth-science teachers, and a proposed program in geochemistry.

The Eastern Section held its *eleventh annual meeting* on April 28-29, 1961, at Colgate University, Hamilton, New York. Forty-six geologists representing 23 institutions were in attendance.

After the annual dinner at the Colgate Inn, J. L. Rosenholtz, Section president, thanked the Colgate geology department for its hospitality. The business meeting followed, in the Faculty Room at the Colgate Library. Maurice B. Rosalsky read the Treasurer's report, which revealed that the Section now has $300.00 in the bank. He also presented the membership report, which showed 9 members dropped and 20 new members. Membership totals 171, the largest in the Section's history. There is strong sentiment in the Section against subdividing it.

The slate of officers presented by the nominating committee (see inside back cover) was elected by mail ballot. J. L. Rosenholtz was elected Section representative on the national nominating committee for 1962. The Section was happy to accept an invitation to meet at Moravian College in the fall of 1961 and at Harpur College for the Spring 1962 meeting.

After the business meeting, Robert M. Linsley spoke on the geology of the Colgate area. The topic of the evening symposium was "Earth Science in the Secondary Schools." Speakers were Donald B. Stone, Samuel N. Namowitz, Allan R. Schutt, and John H. Moss.

On Saturday April 29 the Section held another symposium, entitled "Geochemistry as Taught at the Undergraduate Level." The speakers were Robert M. Garrels, Karl K. Turekian, Heinrich D. Holland, and John W. Winchester. The symposium aroused considerable discussion. The general conclusion was that geochemistry as such should not be taught at the undergraduate level, although much good geochemistry may with profit be scattered through several courses.

The meeting concluded with two afternoon field trips. The Pleistocene along the Chenango River was studied by one group, led by David W. Trainer, and local outcrops of the Hamilton group were visited by the other, under the leadership of Robert M. Linsley.

MAURICE B. ROSALSKY, *Secretary*

EAST-CENTRAL SECTION

The annual meeting of the East-Central Section was held at the University of Notre Dame on May 12-13, 1961.

John B. Patton of Indiana University spoke at the afternoon session, on "Mutual Interests of State Geological Surveys and Universities." Dean Frederick D. Rossini of Notre Dame addressed the evening session on the subject "Academic and Industrial Demands on Today's Undergraduate Students." The University of Notre Dame was host at the annual dinner, a buffet in the Department of Geology.

At the business meeting, the secretary-treasurer's report was accepted as read. Current membership of the Section is 102; balance in the treasury is $72.81. A slate of officers (see inside back cover) was declared elected by mail ballot. Discussion was devoted to several matters in the By-Laws, on which the membership will vote by mail.

On Saturday, Archie MacAlpin conducted a field trip to show glacial and dune features in northwestern Indiana.

G. H. CROWL, *Secretary*

CENTRAL SECTION

The 21st annual meeting of the Central Section was held at the University of Illinois, Urbana, on March 11, 1961.

The business meeting was opened by President Chester O. Johnson. The minutes of the preceding meeting were approved as printed in the Fall 1960 issue of this *Journal*. The treasurer's and auditor's reports were read and approved. A cash balance of $168.85 is on hand. The budget committee recommended regular expenditure of 55 percent of net income for 1961-62. This report was approved.

The nominating committee presented a slate of new officers. In the absence of further nominations from the floor, it was moved, seconded, and passed that these officers be declared elected (see inside back cover). William F. Read was elected representative to the National Nominating Committee.

Vice-President George Wilson suffered a severe illness during 1960-61. Greetings and appreciation were voted to him, and to his staff at the Illinois Geological Survey for assistance in duplicating and mailing meeting announcements prepared by acting Vice-President Hagner.

Thanks were voted to the retiring Secretary.

James Brice stated that he thought better teaching aids should be available from the U. S. Geological Survey, such as an assemblage of descriptions, maps, air-photo stereo pairs, etc., similar to that published by the French National Research Institute. It was suggested that he send a description of what he has in mind to National Vice-President Woodford, for circulation before the November 1961 N.A.G.T. meeting and for discussion there.

Chalmer Roy reported that a slide symposium is planned for the National meeting in November. This symposium will consist of slides taken by geologists participating in the N.S.F.-sponsored tour of the British Isles. The business meeting then adjourned.

The technical program consisted of two parts, *Geology Teaching in the Future* and *Aspects of the Philosophy of Geology and Related Sciences*. The following papers were presented: Chalmer Roy, "The Geology Curriculum of the Future;" James Brice, "Laboratory Experiments for Beginning Geology;" Donald Henderson, "An Integrated Program in the Chemical-Physical Aspects of Geology;" William Hay, "A Program in the Biological Aspects of Geology;" Max Fisch, "Science and Philosophy;" Robert Bader, "Philosophical Aspects of the Biological Sciences;" Aaron Kupperman, "The Impact of Quantum Mechanics on Physics and Chemistry;" Arthur Hagner and Norman Page, "Philosophical Aspects of the Geological Sciences." The after-dinner speaker was Ralph E. Grim, whose topic was "The Future of Geology."

DOROTHY J. GORE, *Secretary*

FAR WESTERN SECTION

The annual meeting of the Far Western Section was held on March 11, 1961, at San Francisco State College. The meeting was

called to order at 9:30 A.M. by the president, Wesley Gordon. The following points of business were discussed.

1. As Clemens A. Nelson will be abroad on sabbatical leave during 1961-62, he has asked to be relieved as Section editor. It was recommended that the new officers appoint his successor.

2. The invitation of A. O. Woodford and Donald McIntyre to meet at Pomona College on April 14-15, 1962, was accepted by the Section.

3. It was resolved that the Newsletter be continued, that the date of distribution be in the fall (send in news with dues), and that responsibility for the Newsletter be assigned to the secretary or editor, as determined by the new officers.

4. Secretary-treasurer Marshall Maddock announced the election of new officers (see inside back cover). There are now 93 paid members of the Far Western Section, including 28 new and reinstated members. The Section's bank balance is about $117.00, with several small bills remaining to be paid.

Vice-President Oliver Bowen introduced the speakers for the morning and afternoon sessions. F. T. Wilmoth of Sierra Junior College spoke on "Some New Techniques in the Teaching of Physical Geology;" J. R. McNitt, California Division of Mines, on "Geology of the Geysers Geothermal Area, Sonoma County, California;" R. C. Richter, California Department of Water Resources, on "Hydrogeology Problems Connected with Importation of Water into the Central Valley of California;" G. B. Oakeshott, California Division of Mines, on "Outgrowths of the Duluth Conference on Geological Education;" E. H. Bailey of the U. S. Geological Survey, on "Feldspar Staining—an Aid in Teaching and Research;" and N. M. Short, Lawrence Radiation Laboratory, on "Applications of Geology to Underground Nuclear Explosions."

The meeting was followed by the annual dinner, at a San Francisco restaurant. Features of the stratigraphy and structural geology of the San Francisco peninsula were studied on a field trip on Sunday.

MARSHALL E. MADDOCK, *Secretary*

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THE NATIONAL ASSOCIATION OF GEOLOGY TEACHERS was founded in the Middle West in 1938. In 1951 it became a national association, under which there are at present nine organized regional sections (see inside of this cover). An annual meeting of the national association is normally held in the fall, and most sectional meetings are held in the spring.

The purpose of the Association, as stated in its Constitution, is "to foster improvement in the teaching of the earth sciences at all levels of formal and informal instruction, to emphasize the cultural significance of the earth sciences, and to disseminate knowledge in this field to the general public."

Anyone concerned with geological education, formal or informal and at any age level, is invited to apply for membership. *Inquiries should be addressed to the national secretary,* DOROTHY J. GORE, Principia College, Elsah, Illinois.

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WAKEFIELD DORT, JR., Department of Geology,
University of Kansas, Lawrence, Kansas

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ROBERT L. BATES, Department of Geology
The Ohio State University
155 South Oval Drive, Columbus 10, Ohio